Journal of
Experimental Psychology

VOL. VII., No. 4 August, 1924

# THE RELATIVE ECONOMY OF VARIOUS MODES OF ATTACK IN THE MASTERY OF A STYLUS MAZE

BY CARL JOHN WARDEN

*Columbia University*

## THE PROBLEM

It has been quite generally assumed that the reactions normally evoked in the process of learning a stylus maze are very largely of the characteristic motor type. In fact the maze has come to be considered the standard apparatus, perhaps, in present laboratory practice, for the study of trial and error motor learning, and especially so in connection with comparative studies. Here the results obtained upon an animal maze are compared directly with those obtained with human subjects upon a stylus maze of similar or identical design. The fundamental assumption seems to be that the human subject in the stylus maze situation must build up a reaction pattern largely in terms of muscular control, in much the same manner as the animal is known to do in maze learning.

Perrin [1] called attention to the fact that the response in the stylus maze situation varied considerably as between individuals, being much less a typical motor response in some subjects than in others. Later Carr [2] found that the effect of giving the subject varying amounts of visual guidance in the early stage of the learning process changed also the type of reaction called out to a marked degree.

[1] Perrin, F. A. C., 'An Experimental and Introspective Study of the Human Learning Process in the Maze,' *Psychol. Review Monog.*, 1914, 16, No. 70.

[2] Carr, H. A., 'The Influence of Visual Guidance in Maze Learning,' JOUR. EXPER. PSYCHOL., 1921, 4, 399–417.

The present study is an attempt to analyze the various modes of attack adopted by subjects who were wholly unbiased and naïve as to the methods that may be employed, and who, therefore, were left to 'hit upon' such modes of reaction as each was able to do, in mastering the situation. In this way it was hoped to determine the extent to which the maze is a typical motor problem in the sense indicated in the opening paragraph. This original problem was broadened in the final treatment of the data to include such other related topics as are indicated below:

1. The distribution of subjects under the various modes of attack adopted.

2. The relative economy of the different methods of learning employed.

3. The factor of *intra-pattern transfer* in learning under motor control.

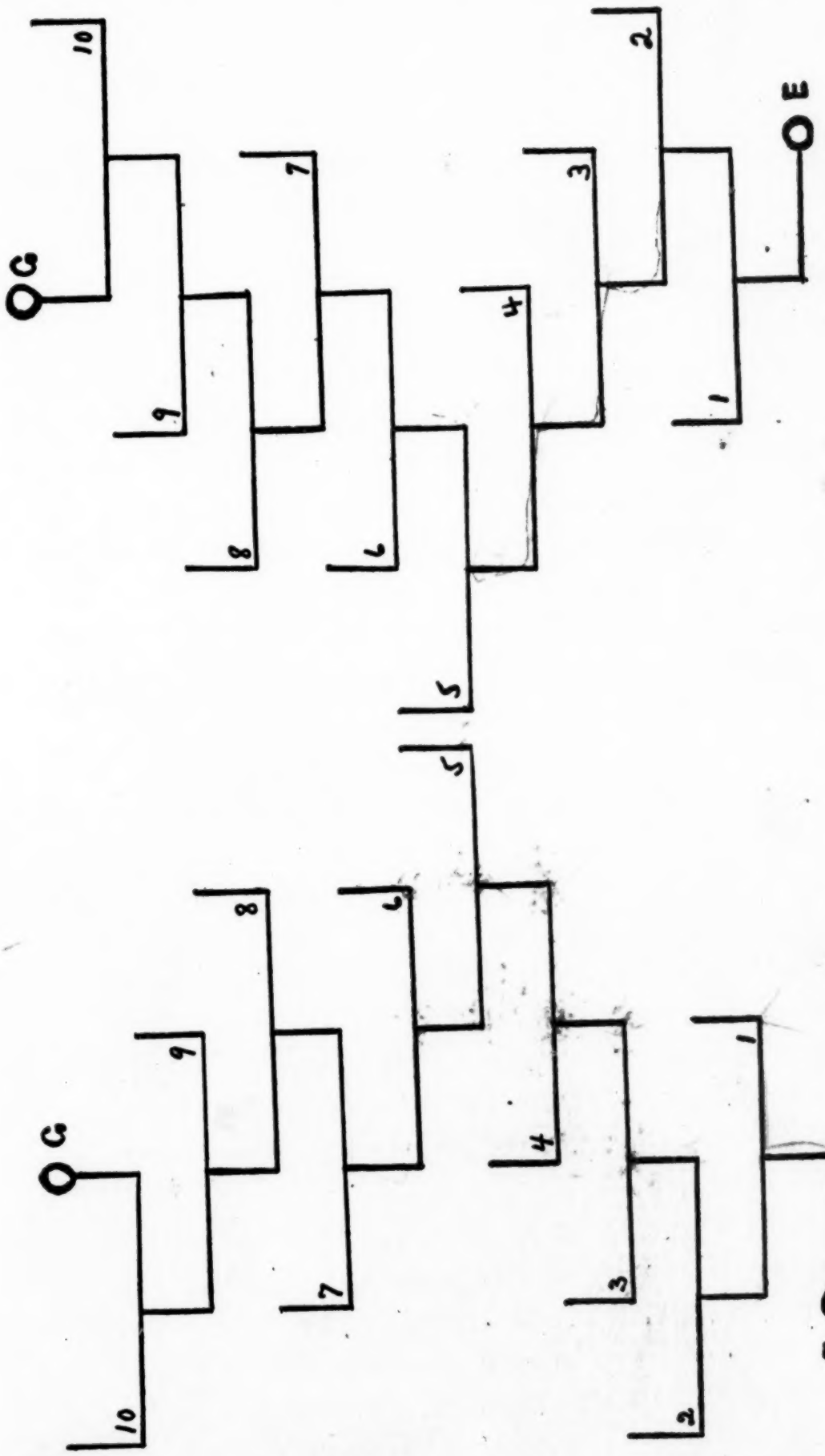
4. An analysis of the so-called visual imagery control.

5. Rank in maze learning in relation to rank in Alpha and Thorndike test scores.

## Apparatus and Method

The two patterns of maze employed are shown in Fig. 1. They were of the usual construction of brass, the quarter inch grooves being cut entirely through the sheet of brass, which rested upon a base of plate glass, thus insuring a smooth surface throughout for the movement of the stylus. The latter was of gutta percha and was provided with a wide flange near the lower end that made it impossible for the hand to come into contact with the maze at any point.

The mazes, each of which measured $10\frac{1}{4}$ by $11\frac{1}{4}$ inches in size, were securely fastened to a table with a 24 by 36 inch top and which was approximately 30 inches high. Instead of blindfolding the subject, the maze together with the entire top of the table was hidden from the view of the subject by means of a cloth-covered frame 20 inches in height which made an effective hood. Directly in front of the subject the curtain of the hood was held outward in such a manner as to permit a free and easy movement of the arm in operating




Pattern 2




Pattern 1

Fig. 1

the stylus, when extended through this opening. The subject seated himself directly in front of the maze in a comfortable position as if for writing upon the table.

For a more elaborate description of the apparatus, and for a statement of the method used in the scoring of errors at each of the 10 culs de sac, the criteria of error elimination employed, etc., reference may be had to an article appearing in a previous issue of this journal.[1]

Particular attention is called to the fact that in no case was information concerning either the nature of the task or the manner of its performance given verbally to the subject. Upon first entering the room each subject was handed a sheet of typed instructions giving a brief general description of a stylus maze situation, the starting and stopping signals, a few precautions concerning the proper method of holding the stylus, and other similar information. The problem itself was stated to be, 'learning to go from the entrance to the goal without making any false turns into blind alleys, for three trials out of four in succession.'

The subject was informed at the bottom of the page not to ask questions of the experimenter, to read the instructions over at least twice, and to indicate when he was ready to begin. In a few cases the subject did ask the experimenter 'just how he should go about it to learn,' etc., but such questions were always answered by the experimenter merely by a typically Continental shrug of the shoulders. Each subject approached the problem, therefore, with exactly the same opportunity of informing himself as to the nature of the situation, and the manner of meeting it was left entirely to his own ingenuity.

This rigid technique, in which not a single word concerning the task was uttered by the experimenter in the presence of the subject previous to the learning, makes it impossible that the results obtained are in any measure due to suggestion or immediate laboratory atmosphere. Inasmuch as it was the intention to determine whether or not any relation exists between the intelligence scores of the subjects and the mode

[1] Journ. of Exp. Psych., April, 1924, 98–116.

of attack that they might 'hit upon' in learning the maze, the importance of the technique concerned with the preconditions of learning can hardly be overemphasized.

After the problem had been mastered the subject was handed a sheet of paper on which had been typed a brief description of the 3 following methods of learning, with instructions to check their use, in the order of their importance, in the present situation: Word reaction method, Visual imagery method, Motor method. He was also instructed to describe, in blank spaces provided, any method or methods which he may have used that seemed to him to be different from either of the three listed. This was the first intimation given the subject that the experimenter was in any way interested in the manner of his attack in learning the maze.

After the questionnaire had been checked, the subject was questioned verbally by the experimenter as to precisely what he had meant by indicating that he had used this, that or the other method in learning. He was also required to describe or illustrate the operation of the method or methods as applied to his own case. Occasionally the subject decided that he had made an error in checking the questionnaire, in which case he was allowed to make a correction. The error arose, of course, from the fact that the descriptions of the different methods on the questionnaire had not been adequate in such cases. Changes in the original check after the verbal questioning occurred, however, in less than 5 per cent. of the cases, and most often involved the addition of a second method that had been used to some extent, rather than a change in the matter of the method primarily used. Since the classification of subjects into response types in the present report was made altogether on the basis of the mode of attack primarily employed, this recheck of the questionnaires is inconsequential in determining the general outcome of the results.

Perhaps a word should be said about the forms of reaction involved by each of the three methods as here interpreted. Under the term 'word reaction' was included attempts to

the stylus, when extended through this opening. The subject seated himself directly in front of the maze in a comfortable position as if for writing upon the table.

For a more elaborate description of the apparatus, and for a statement of the method used in the scoring of errors at each of the 10 culs de sac, the criteria of error elimination employed, etc., reference may be had to an article appearing in a previous issue of this journal.[1]

Particular attention is called to the fact that in no case was information concerning either the nature of the task or the manner of its performance given verbally to the subject. Upon first entering the room each subject was handed a sheet of typed instructions giving a brief general description of a stylus maze situation, the starting and stopping signals, a few precautions concerning the proper method of holding the stylus, and other similar information. The problem itself was stated to be, 'learning to go from the entrance to the goal without making any false turns into blind alleys, for three trials out of four in succession.'

The subject was informed at the bottom of the page not to ask questions of the experimenter, to read the instructions over at least twice, and to indicate when he was ready to begin. In a few cases the subject did ask the experimenter 'just how he should go about it to learn,' etc., but such questions were always answered by the experimenter merely by a typically Continental shrug of the shoulders. Each subject approached the problem, therefore, with exactly the same opportunity of informing himself as to the nature of the situation, and the manner of meeting it was left entirely to his own ingenuity.

This rigid technique, in which not a single word concerning the task was uttered by the experimenter in the presence of the subject previous to the learning, makes it impossible that the results obtained are in any measure due to suggestion or immediate laboratory atmosphere. Inasmuch as it was the intention to determine whether or not any relation exists between the intelligence scores of the subjects and the mode

[1] Journ. of Exp. Psych., April, 1924, 98–116.

of attack that they might 'hit upon' in learning the maze, the importance of the technique concerned with the preconditions of learning can hardly be overemphasized.

After the problem had been mastered the subject was handed a sheet of paper on which had been typed a brief description of the 3 following methods of learning, with instructions to check their use, in the order of their importance, in the present situation: Word reaction method, Visual imagery method, Motor method. He was also instructed to describe, in blank spaces provided, any method or methods which he may have used that seemed to him to be different from either of the three listed. This was the first intimation given the subject that the experimenter was in any way interested in the manner of his attack in learning the maze.

After the questionnaire had been checked, the subject was questioned verbally by the experimenter as to precisely what he had meant by indicating that he had used this, that or the other method in learning. He was also required to describe or illustrate the operation of the method or methods as applied to his own case. Occasionally the subject decided that he had made an error in checking the questionnaire, in which case he was allowed to make a correction. The error arose, of course, from the fact that the descriptions of the different methods on the questionnaire had not been adequate in such cases. Changes in the original check after the verbal questioning occurred, however, in less than 5 per cent. of the cases, and most often involved the addition of a second method that had been used to some extent, rather than a change in the matter of the method primarily used. Since the classification of subjects into response types in the present report was made altogether on the basis of the mode of attack primarily employed, this recheck of the questionnaires is inconsequential in determining the general outcome of the results.

Perhaps a word should be said about the forms of reaction involved by each of the three methods as here interpreted. Under the term 'word reaction' was included attempts to

memorize the direction and order of the turns by attaching verbal symbols to them. The most characteristic response under this method was to verbalize the number of turns in one direction, then the number in the opposite direction, and so on through the series. The visual imagery method involved a reported attempt on the part of the subject to determine the direction of the turn at each point by referring to a more or less complete visual image of the maze pattern. Under the motor method the selection of direction was understood to be largely in terms of the kinesthetic modality; a muscular control being used rather than either a verbal or an imaginal one. These distinctions were made as simple and non-technical as possible in defining the nomenclature of method used on the questionnaire.

Of a total of 60 subjects taking the experiment, 46 were students of Columbia College, all of whom had taken or were taking a course in elementary psychology; 1 was a student of Barnard College; the remaining 13 included for the most part graduate students in psychology in Columbia University.

## The Results

I. *The Distribution of the Subjects under the Three Methods.*—In the first column of Table I. is presented the number of subjects who, left entirely to themselves, in some manner hit upon and adopted each of the three modes of attack. The percentages covering the same item appear in the second column.

### Table I

Relative Economy of Various Modes of Attack

| Mode of Attack | Number of Subjects | Per Cent. of Total Number | Trials Required to Learn | |
|---|---|---|---|---|
| | | | Mean | Range |
| Word Reaction..... | 25 | 41.7 | 32.2 | 16–62 |
| Vis. Imagery..... | 18 | 30.0 | 67.9 | 41–104 |
| Motor Reaction..... | 17 | 28.3 | 123.9 | 72–195 |

It was a matter of some surprise to the writer to find that so small a number of the subjects should use primarily the

motor method, the actual number being somewhat less than 30 per cent. of the entire group. A slightly larger percentage reported an attempted visualization of the pattern, while approximately 42 per cent. reduced the spatial situation to a verbal scheme of some sort and memorized the verbal series.

It ought to be mentioned in this connection, perhaps, that the majority of the subjects reported the use of more than a single method, and that the values given in the above table are based upon the method *primarily* used. When a second method was reported it was definitely assigned to a place of lesser importance by the subject, and meant merely that at sometime during the learning this subsidiary mode of attack had been tried out but later rejected and replaced by the primary method. The method upon which the above classification is based was always, therefore, the one that finally brought success. While it is interesting to know that most of the subjects set about from the first to find short-cut methods of meeting the situation, those that proved to be of little or no aid to the subject and were on this account discarded by him, hardly merit separate treatment and have been altogether ignored in this report.

If the comparisons presented in the first two columns of Table I. may be taken as typical of stylus maze learning in general, it is apparent that the characteristic motor reaction is not called out by the stylus maze situation in any but a small minority of individuals, and even many of these may depend in part upon other than motor cues. And if this be true, then the validity of the common practice of making direct comparisons between the data of stylus maze learning, on the one hand, and animal maze learning upon the other, may very properly be called in question. At any rate such a comparison should not involve the assumption that the mode of attack and the type of response are similar in the two cases. For it appears that the human subject as the usual thing utilizes short cut methods that are not included in the animal's *repertoire* of response, such as 'attempts to visualize,' and verbalization. The animal must depend upon sensori-motor cues. The large percentage of subjects making use of

verbalization of some sort in the present experiment suggests that stylus maze learning may be more a matter of arranging a series of words into a definite order and then fixating them, than of moving the arm about under motor control.

It may be objected that the small percentage of individuals using the motor method in the present experiment may be in part a function of the particular pattern of maze employed; that the simplicity and uniformity of this maze would favor the calling out of other than the motor type of response. This does not seem very probably, however, inasmuch as it will be shown later that the maze was not apprehended by the subject as being simple or uniform. In cases in which the maze was shown to groups after the learning, expressions of surprise were practically unanimous, since everyone had thought of it as being much more differentiated and complex than it actually was.

Furthermore, this maze proved to be extremely difficult to learn in comparison with other stylus mazes that have been used by various experimenters. The average number of trials required to learn, when all three groups are thrown together is approximately 69, while the range in number of trials runs from 16 to 195. Less than half as many trials would be required on one of the more usual patterns. There seems to be no valid reason, therefore, for not considering the results here obtained as typical of stylus maze learning in general, although it would be desirable to test out different and more complex patterns, using the same rigid technique as was here employed.

II. *The Relative Economy of the Three Modes of Attack.*— The data covering this point are given in the last three columns of Table I. The relative economy of the word reaction method in comparison with either of the other two methods is very evident. Only about $\frac{1}{2}$ as many trials were required on the average in this group as in the visual imagery group, and only about $\frac{1}{4}$ as many as in the motor reaction group. An inspection of the range will show that there was no overlapping whatsoever between the word reaction group, on the one hand, and the motor reaction group on the other.

The slowest subjects of the former group made better records than the fastest of the latter group. The motor method proved to be extremely uneconomical therefore, in the case of every subject who depended upon it. The reasons for this will appear in connection with the later discussion.

Upon purely theoretical grounds it should be expected that the word reaction method of learning would be more economical than other and more primitive types, regardless of the specific nature of the problem to be solved. In the stylus maze situation as in other motor situations, it involves the substitution of fine muscle reactions of the vocal cords and larynx for the coarser reactions of the skeletal musculature. At least this is true insofar as the matter of the *control* of the movement is concerned. The arm-hand set of muscles merely follows about the grooves in the directions indicated by the series of verbalizations. It is a *verbal* rather than an arm-hand muscular control.

An example of the operation of the word reaction method will serve to illustrate how widely it differs from the motor mode of attack. One subject repeated in audible whispers the following word scheme in learning pattern I.: 'right-forward, and left-forward, then right-forward three times, left-forward twice,' and so on through the maze. Curious mixtures of symbols representing form, number, direction, and position occurred in the word schemes of some subjects. Thus, one subject in describing his experience in threading the true pathway said, "Well, I made a U-shaped turn at the entrance, then three turns away out to the right, then I found I had to drop back a couple of places," etc. Naturally each subject had his own memory scheme, but all were essentially alike in being a series of conventional symbols, attached to the critical points of the pattern, which served to determine the direction the arm should take in following the groove at each point.

Each of the 25 subjects who were included in the word reaction group actually reported some such verbal scheme to the experimenter after they had mastered the maze. In some cases the verbalization was explicit, in fact could be heard

by the experimenter during the learning process, while in other cases it seemed to be largely, if not wholly, implicit.

It is clear from the above analysis that the arm operating the stylus, under the word reaction method, does not need to form a habit in terms of the kinesthetic modality, as is of course true when a motor attack, and hence a muscular control, is employed in learning. The cues that determine the direction of movement are verbal, and the arm-hand musculature, of primary importance in learning a maze by the motor method, is subordinated to the relatively unimportant rôle of merely following the verbal cues.

Moreover, these verbal cues of number, direction, form, position, etc., are in turn pre-formed habit patterns of the vocal musculature, which on account of their frequent usage are almost as easily set off as reflexes. They do not need to be learned at the time, but only appropriated and arranged in a series corresponding to the turns in the pathway of the maze which they represent. The arm has also previously been trained to follow these common verbal symbols of direction, such as 'left,' 'right,' 'forward,' etc., so that the coördination between the musculature of the vocal organs, on the one hand, and that of the arm-hand set on the other, offers small difficulty.

The vast saving effected under the word reaction mode of attack seems, therefore, to lie in the fact, first, that there is a substitution of a pre-formed unit response pattern of the verbal type for the arduous task of building up at each point, an actual arm-hand muscle coördination pattern; and second, that the total serial response in the former instance, as in the case of other simple memory series, involves only temporal pattern,[1] whereas in the motor situation the total response is unified by means of a spatial pattern which must also be incorporated into the total movement of threading the maze.

That the spatial pattern of the maze does actually play a more important rôle in the motor than in the verbal method, is not a matter of mere theoretical analysis, but is fully substantiated by certain objective data obtained in the present

[1] *Op. cit.*

experiment. In any case in which pattern might prove to be a small factor there should be a correspondingly small variation in relative difficulty between various parts of the pattern; one cul de sac should be entered about as often and eliminated at approximately the same time as another, subject to the operation of such laws as primacy and recency which do not depend upon spatial but upon serial position. On the other hand, in cases in which the particular spatial configuration of the maze pattern must be reduced to movements of definite distance and direction, this emphasis upon pattern should be indicated in a wide variation in relative difficulty of different parts of the pattern. This variation should be small, therefore, for the word reaction group and very much larger for the motor group.

TABLE II

RELATIVE VARIATION IN DIFFICULTY OF CULS DE SAC IN TERMS OF TOTAL TIMES ENTERED

| Number of Cul de Sac. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Variation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Word Reaction..... | 1.0 | 1.3 | 2.8 | 4.5 | 1.7 | 2.5 | 4.5 | 2.4 | 4.5 | 1.6 | 450% |
| Vis. Imagery..... | 3.7 | 1.0 | 7.2 | 9.0 | 3.2 | 8.0 | 13.8 | 1.5 | 9.8 | 3.2 | 1380% |
| Motor Reaction..... | 6.7 | 4.9 | 14.5 | 20.9 | 12.3 | 17.3 | 28.0 | 1.0 | 23.7 | 13.3 | 2800% |

*Legend:* The cul de sac entered the least number of times in each of the three groups is assigned the value of 1, the values for the other culs de sac of the group being based thereon.

TABLE III

RELATIVE VARIATION IN DIFFICULTY OF CUL DE SAC IN TERMS OF THE NUMBER OF TRIALS REQUIRED TO ELIMINATE

| Number of Cul de Sac. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Variation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Word Reaction..... | 1.0 | 1.0 | 2.7 | 3.9 | 1.1 | 2.1 | 3.9 | 1.5 | 3.8 | 2.0 | 390% |
| Vis. Imagery..... | 2.4 | 1.0 | 4.4 | 6.9 | 1.8 | 4.4 | 8.0 | 1.2 | 5.0 | 2.3 | 800% |
| Motor Reaction..... | 3.2 | 2.4 | 5.9 | 9.0 | 2.7 | 4.2 | 19.7 | 1.0 | 6.4 | 5.3 | 1970% |

*Legend:* The cul de sac requiring the least number of trials for elimination in each group has been assigned the value of 1, the values for the other culs de sac of the group being based thereon.

Precisely such a relation is shown by the data presented in Tables II. and III. The values of Table II. were obtained by determining the ratio between the total number of en-

trances into each of the ten culs de sac, for a group representing a given method, and the number of entrances into the cul de sac least entered by the group taken as unity. These ratios are, therefore, indices of variation in difficulty of various parts of the pattern, the range of variation for each of the three groups being given in percentages in the last column of the table. Table III. presents ratios similarly obtained, based upon the absolute number of trials required to eliimnate the various culs de sac under the three modes of attack.

We are not concerned here with the matter of why this, that, and the other cul de sac differs from some other in difficulty, but with the most significant fact that *the range of variation in difficulty of culs de sac is apparently a function of the mode of attack used in learning the maze.*

The range of variation in total entrances proved to be more than six times as great on the average when the subject employed the motor reaction method as when the word reaction method was used, the value for the visual imagery group standing approximately mid-way between the other two. The same general relationship also obtained when the number of trials required to learn is used as the basis of comparison. Since all other conditions of the experiment were precisely the same for each group, except the mode of attack voluntarily adopted, the interpretation of these differences in variation can be made only in terms of the variable rôle played by the factor of spatial pattern under the three methods of mastery. This means that the factor of pattern is relatively inconsequential under the word reaction method when compared with either of the other two, and extremely so with respect to the motor method. And this is precisely what we should expect.

This same relationship is further illustrated by a study of the differential behavior of subjects learning the maze by different modes of attack, in their attempt to make a reproduction of the true pathway immediately after the last trial. Before the subject had shifted his bodily position, he was handed a pencil by the experimenter beneath the hood, and told to, 'grasp the pencil as if it were the stylus, and execute

the movement of going correctly through the maze, on a large sheet of graph paper, with no grooves to guide the pencil.'

The sheet of paper was much larger than the maze to allow for any possible exaggeration in the reproduction, and was fastened to a heavy piece of cardboard placed directly on top of the maze. The only difference between this exercise and actually running the maze lay in the absence of grooves to guide the pencil, and in the absence of a flange on the pencil, which served as a rest for the fingers when the stylus was used. The same pencil was employed for all subjects, however, so this latter factor may be ignored.

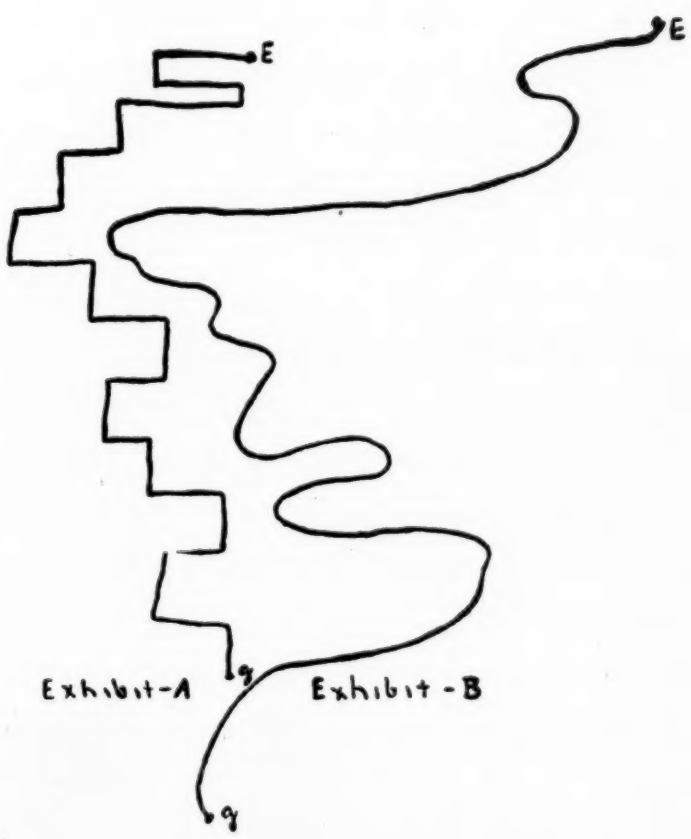



FIG. 2.

A typical record when the word reaction method had been used in learning is shown as exhibit *A* of Fig. 2, while the motor method is characteristically represented there by exhibit *B*. Inasmuch as the visual imagery method gave no typical record, other than usually a mixture of the word reaction or motor type, when not purely of the one or the other type, a sample record has not been included for this group.

The dependence of the motor learner upon the 'feel' of the grooves is very apparent. When deprived of the cues that arise from the pathway itself, the subject is almost hopelessly lost. Instead of angular turns truly depicting the configuration of the pattern, we get only the merest waves in the line for all but a few turns, and these few turns, corresponding to the dominant errors in learning the maze, are exaggerated out of all proportion. But this is only a graphic representation, characteristic of the motor reaction group as a whole, of the fact previously developed, *i.e.*, that a wide variation occurred in the rôle played by various parts of the pattern, when the learner depended upon simple sensori-motor cues.

The parts that proved to be especially difficult, and are represented by the large outstanding turns in the record under discussion, were those places in the maze pattern at which the subject could not follow the one or the other wall of the groove further without running pell mell into a cul de sac. This meant that at these few points a definite avoidance reaction pattern involving a change of direction must be gradually built up in terms of the arm-hand set of muscles. Turns between these points tended to be ironed out in the record because the movement of the stylus along the edge of the groove was unusually rapid, with an abrupt stop at these critical positions. In general the greater length and sprawling character of the record betrays the coarse arm-hand muscular control.

The record representative of the word reaction method of learning hardly needs analysis. The angular turns throughout would naturally result from the somewhat slow and deliberate movement in learning, in which the unit movements corresponding to a given symbol of the word scheme were more or less separated from each other by a slight pause. The comparative uniformity of the turns would seem to indicate the slight effect of spatial pattern when a word scheme is used, and this agrees with the fact that only a relatively small variation in difficulty between different parts of the pattern obtained with this group as was indicated also by the quantitative data already presented.

## TABLE IV

RELATION BETWEEN MODE OF ATTACK AND TYPE OF MAZE PATTERN REPRODUCTION

| Mode of Attack | Number of Subjects | Type of Maze Pattern Reproduction | | |
|---|---|---|---|---|
| | | Word Reaction | Motor | Mixed |
| Word Reaction | 25 | 20 | 0 | 5 |
| Vis. Imagery | 18 | 5 | 5 | 8 |
| Motor Reaction | 17 | 0 | 13 | 4 |

In Table IV. the number of the reproductive records that were found to be typical of the two groups under discussion has been given. The classification was made on the basis of the number of angular turns occurring in the record, this seeming to represent the essential difference between the two types better than any other single characteristic of the records. Those showing a total absence of angular turns were classed as motor; those having 6 or more angular turns as word reaction; the remaining ones as mixed.

In no case did a record of the group using the word reaction mode of attack classify as motor, nor a record of the group using the motor method classify as word reaction in type, although both groups showed approximately 20 per cent. of the mixed class. The visual imagery group on the other hand included an equal number of both types, the remaining 45 per cent. classifying as mixed.

Although it has been necessary to emphasize the verbal nature of the control in the case of the word reaction method, to differentiate it sharply from the motor mode of attack, it must not be supposed that we have meant to reduce the process of learning a stylus maze by the former method to the mere fixation of a series of words, such as would be the case with rote memory material. Each turn in the maze must be discovered by the operation of the stylus before it can be labelled right, or left, or forward, etc. Once a turn has been discovered and labelled and assigned to its position in the series of words, which when complete must correspond

to the actual configuration of the true pathway, then it probably does become a matter of mere verbal memory.

The problem of discovering consecutive directions and of locating definite points under the non-visual conditions imposed in stylus maze learning is not such an easy task as might appear to the uninitiated. For example, when a false turn has taken the subject off the true pathway and into a cul de sac, it is difficult for the subject to be certain, upon attempting to retrace, when he has reached again the point at which he left the pathway at first. In the meantime the error may have caused the subject to forget his exact position in the word scheme, and hence he must continue the effort by repeated trials to work out a perfect word scheme.

In learning a series of nonsense syllables or words, then, the exact scheme to be learned is given, whereas in the present case it must be discovered by typical trial and error methods bit by bit. The latter process evidently requires many more trials than the former, since a series of ten or twenty words could easily be fixated in a given order by six or eight repetitions at most, whereas the discovery and fixation of the maze pattern by the word reaction method required over thirty trials on the average.

In this connection it ought to be pointed out, however, that short cut methods were perhaps not used at the beginning of the learning by any of the subjects. The first trial must necessarily call out a typical motor response. This mode of attack was therefore favored by the fact that all depended upon it at first. The situation calls for hit and miss exploration at this stage of learning in getting the general form of the maze and the approximate location of the goal. After this mode of attack has proven unsuccessful in cul de sac elimination, the subject is then more likely to try out some short cut device. Much effort was wasted in some cases, no doubt, before the word reaction method was 'hit upon' and successfully used by the subject. If the method had been used from the first, by the subjects who finally came to depend upon it, an even greater saving over other methods would doubtless have been effected.

III. *The Factor of Intra-Pattern Transfer in Motor Control.* —The results already discussed indicate the relatively large rôle played by spatial pattern in learning the maze by the motor method. The more fundamental problem remains unsolved, as to the specific factors in the motor situation that operate to disturb and prolong the period of learning to so great an extent as occurred in the present instance. Doubtless many factors are involved, the isolation and measurement of which may appear to be an almost impossible task. Such an analysis of the situation, however, is most necessary to an adequate understanding of the essential mechanism of motor response.

In the present experiment it has been possible to isolate one of the very important factors operating to make the motor method of attack uneconomical. A differential form of behavior between the verbal and motor types of subject was observed in the actual process of mastery, and this difference was of such a nature as to appear in a very marked manner also in the detailed error records. A statistical treatment therefore became possible.

The particular behavior observed, and which was characteristic of the motor method of attack, consisted essentially in a definite carrying over absolutely unchanged of the specific series of movements being made at a given stage of learning, to a later stage where an attempt was being made, consequent upon the dropping out of some cul de sac, to make a readjustment in the pattern of the motor response. This carrying over of the response pattern from an earlier to a later stage of mastery of the maze is obviously, a special case of transfer of training, but it is transfer *within a single complex integration* rather than between various mazes, or other problems, learned at different times and under different conditions. It has seemed to the writer that this carrying over of parts of the reaction pattern from one stage of a developing habit to another, no previous description of which appears to have been reported in the literature in connection with the stylus maze or other forms of human motor situa-

tions,[1] might very properly be termed *intra-habit*, or *intra-pattern* transfer. Whether this transfer be positive or negative would seem to depend upon the specific arrangement of culs de sac in the maze employed. All the cases that have been checked in the present instance proved to be negative in character, and the term *intra-pattern interference* has been used interchangeably with that of *intra-pattern negative transfer* throughout the later discussion.

This particular type of obstruction in motor habit formation occurred especially frequently in the two following instances: First, when the maze was so placed that culs de sac 2, 3, 4, 7, and 10 were located opposite the hand operating the stylus, and all culs de sac excepting numbers 3, 4 and 7, or 3, 4, 7, and 10 had been successfully eliminated by the subject, the sudden avoidance of either number 3 or number 4 caused number 6 to be consistently entered although it had been previously eliminated. A slight variation sometimes occurred in that the stylus was moved to the entrance of number 6, whereupon the direction would be reversed and number 5 entered with a quick backstroke movement. Second, when the position of the maze was such that culs de sac 1, 5, 6, 8, and 9 were located opposite the hand operating the stylus, and all culs de sac excepting numbers 3, 4, 6, and 9 had been eliminated, a similar avoidance of either number 3 or number 4 also caused number 5 to be entered in a manner similar to that above indicated, while the avoidance of number 6 led to the entering of number 7, which had been previously eliminated, also by a backstroke retracing movement.

The specific nature of the mechanism of movement involved in these two examples of intra-pattern interference has been indicated in Table V. The principle applying in both cases is the same. The movement made in avoiding culs de sac 3 or 4 or 6 is merely interpolated between two unit movements of the old reaction pattern and the latter series of turns is then unwound with mechanical exactitude

[1] Prof. H. A. Carr has observed a highly similar or identical type of reaction in the case of the white rat, in the maze. See his article 'The Distribution and Elimination of Errors in the Maze,' *Jour. Animal Behav.*, 1917, VII., 145–159.

## TABLE V

TWO EXAMPLES SHOWING THE OPERATION OF INTRA-PATTERN NEGATIVE TRANSFER IN DETAIL

| Unit Movements of Reaction Pattern in Old Situation | Serial Order | Unit Movements of Reaction Pattern in New Situation |
|---|---|---|
| Right—along true-pathway to cul. 3 | I | Right—along true-pathway to cul. 3 |
| | | *Right—along true-pathway to cul. 4 |
| Left—into cul de sac 3 | 2 | Left—into cul de sac 4 |
| Right—out of cul de sac 3 | 3 | Right—out of cul de sac 4 |
| Right—along true-pathway to cul. 4 | 4 | Right—along true-pathway to cul. 5 |
| Left—into cul de sac 4 | 5 | Left—along true-pathway to cul. 6 |
| Right—out of cul de sac 4 | 6 | Right—into cul de sac 6 |

EXAMPLE II

| | | |
|---|---|---|
| Left—along true-pathway to cul. 6 | I | Left—along true-pathway to cul. 6 |
| | | *Left—along true-pathway to cul. 7 |
| Right—into cul de sac 6 | 3 | Right—along true-pathway to cul. 8 |
| Left—out of cul de sac 6 | 3 | Left—retracing pathway to cul. 7 |
| Left—along true-pathway to cul. 7 | 4 | Left—backstroke into cul. 7 |

*Legend:* The movement preceded by a star in each example is the interpolated avoiding movement. Aside from this movement the two series are alike so far as direction of turning each time is concerned. But on account of this added movement, the transfer of the series of turns from the old to the new situation causes number 6 to be entered in example I, and number 7 in example II.

just as if this new movement, so interpolated, had not been made at all. But the new avoiding movement has necessarily changed the locus from which the series of movements of the old pattern which follow it begins to unwind. On account of the failure to make allowance for this change in position, the automatic reeling off of the unit movements of the total response pattern of the moment causes each of those movements which follow the interpolated avoiding movement, to come within a different section of the maze than before, and the entering of certain culs de sac further down the pathway is the inevitable result.

For example, the subject starts out from the maze entrance going through a series of right and left turns which represent the reaction pattern at that stage of mastery. But instead of turning into cul de sac number 3 as usual, he hesitates, then goes the opposite direction along the true pathway to a position at the entrance of cul de sac 4. Then, utterly heed-

less of the fact that he is now at number 4 instead of number 3, he begins to reel off the old reaction pattern that he had dropped a moment before at number 3. The series of turns from cul de sac 3 in his muscular habit runs Left, Right, Right, Left, as can be seen by referring to the first column of Table V. From his changed position at number 4, however, such a series of turns leads directly into cul de sac number 6, as will appear from the second column of the same table.

The backstroke movement into number 5 which sometimes occurred instead of the usual entry into number 6, under the above conditions, may be explained as follows: the movement leading up to the entrance of number 6 (see second column of Table V.) would correspond to the movement into number 4 in trials previous to the interpolation of the avoiding movement; but the movement into number 4 (or any other cul de sac for that matter) comes in the later trials to include only *partial* entry followed by a reversal of direction; the same type of movement in approaching number 6 would mean that this cul de sac would not be quite reached, a reversal of direction naturally leading to the backstroke retracing movement into number 5 as often occurred. The transfer is just as fixed and definite in this case as when number 6 is actually entered.

The other instance mentioned in which the avoidance of number 6 involved the automatic entry of number 7 can be explained on the same basis, as well as still other cases which occurred less frequently. The culs de sac which were reëntered under this condition often proved difficult to reëliminate. For, the fixation of the interpolated movement which meant the successful elimination of one cul de sac usually meant repeated entry into the one newly reacquired. In several instances the latter appeared consistently in the error record of a subject for as many as 50 or more trials. In other cases the reëntered cul de sac was reëliminated after only a few trials, although this was by no means the rule.

An examination of the records, which were kept in such detail as to show the direction and extent of every movement

made within the maze by each subject during the entire period of mastery, shows very clearly that intra-pattern interference is limited almost entirely to the latter half of the learning process. It occurs usually in connection with the elimination of the more difficult culs de sac that have become relatively fixed in the response pattern. Thus numbers 3 and 4 and 6 were among the hardest to eliminate in the maze here used, and one or another of them was also involved in this interference phenomenon in the case of every subject of the motor group.

This interference was noticeably present in the case of only one subject of the word reaction group, the one requiring 62 trials to learn, and therefore making the most uneconomical record of this group, and in this case the motor method had been used as a secondary method. It was indicated in the error records of every member of the motor reaction group, and usually to a very marked extent especially where a large number of trials had been required to learn, where it operated no doubt as a causal factor in prolonging the period of mastery. While its influence was manifested to some extent in the records of approximately two thirds of the subjects comprising the visual imagery group, its presence appeared to decrease consistently with a decrease in the number of trials needed to master the maze. The exact data covering its occurrence are given in Table VI.

## TABLE VI

RELATION BETWEEN MODE OF ATTACK AND THE OCCURRENCE OF INTRA-HABIT NEGATIVE TRANSFER

| Mode of Attack | Transfer Present | Transfer Absent |
|---|---|---|
| Word Reaction | 1 | 24 |
| Vis. Imagery | 13 | 5 |
| Motor Reaction | 17 | 0 |

The results show that the amount of intra-pattern transfer increased consistently with the number of trials required to learn the maze. Since the transfer was negative so far as observed in the present instance, it might be assumed that it was altogether causal in its relation to the slow rate of learning

obtaining in cases in which it occurred. However, such can hardly be the case. The fact seems to be that there must first be a slow learning over a period of time; a fairly firm fixation of a definite response pattern, which must include a few persistent errors, must be developed in the motor organization, or else there will be nothing definite enough to transfer.

In case a problem can be mastered in a few trials, whether a very simple one by the motor method, or a more complex one by a short cut method, this transfer factor could hardly be consequential. In such cases the correct series of movements are successfully integrated before any definite erroneous patterns are developed and fixated. The correct serial movement arises directly and immediately out of the *milieu* of random movements, none of the errors being persistent. In brief, the first pattern to be fixated is the correct one and nothing is required to be unlearned.

It is only when the problem is too difficult, or the mode of mastery too slow to be thus effective; when certain persistent errors become fixated in the general response pattern by frequent repetition; when, therefore, there is a definite motor organization of the arm-hand musculature to be carried over, that the interference of the type here described can take place to any appreciable extent.

In this sense, therefore, the interference is dependent upon, and not the cause of, the long period of mastery or the slow rate of learning. This is clearly shown by the fact that the interference occurred only in the case of relatively slow learners, and then after random movements had given place to an oft-repeated serial movement in traversing the maze, in the middle and later stages of the process, in which the elimination of persistent culs de sac constituted the main problem. After this latter stage had been reached, however, the interference factor must have played an important part in further prolonging the period of mastery, inasmuch as in many cases the reëntered culs de sac became again fixed and were often difficult to eliminate.

From the present incomplete analysis, there seems to be two outstanding factors that are mutually coöperative in

lowering the economy of motor control in the stylus maze situation. First, the natural tendency of the subject under this method to follow the wall of the groove opposite the hand [1] leads to the early elimination of all culs de sac excepting those few into which this practice must cause him to enter pell mell. By the same token, these latter culs de sac are emphasized by frequent entry, and become fixated in the reaction pattern also relatively early in the learning process. This dominancy of a few culs de sac is clearly shown by the extreme variation in difficulty among them under the motor method, in comparison with the other two modes of attack, as has been pointed out in the discussion of Tables II. and III. The graphic records of Fig. 2 also offer corroborative evidence on this point.

Second, such an early formation of a definite reaction pattern, from which it would be relatively difficult for the subject to break away, is precisely the best possible condition for the operation of the factor of intra-pattern transfer. The reaction pattern, including consistent entry into these few dominant culs de sac, has become more or less automatized under the control of the arm-hand set of muscles. A new movement suddenly made in avoiding one of these culs de sac does not at first break up the old pattern; it is merely interpolated, the old series of turns—the old rhythm of movements—being gone through with exactly as before. The inevitable result of thus carrying over the reaction pattern of an earlier to a later stage of learning, in the case of the maze here employed, was pell mell reëntry into certain other culs de sac further along the pathway.

The word reaction mode of attack, on the other hand, does not involve the tendency, so prominent in the motor method, of following the grooves in the same mechanical manner trial after trial with the consequent emphasis upon, and fixation of, a certain few culs de sac. There is no arm-hand habit to carry over and hence there could not well be transfer of the sort here described. In fact, the maze is mastered in so few trials that there is small chance for any

[1] *Op. cit.*

particular error to become unduly fixated, and without the reaction pattern at any given stage becoming set.

The transfer seems to be much more definite and automatic in the stylus maze than in the animal maze situation. Carr [1] observed a tendency for the white rat to fixate a new cul de sac in eliminating an old one in much the same manner as we have here described. He states, however, that in the case of the animal the fixation of the new one, consequent upon the elimination of the old one, was preceded by 'indecision and alternation for a short period' followed by sudden fixation. No such indecision occurred in the behavior of the human subject in the stylus maze situation. On the contrary, the very first time the avoiding movement was interpolated in the attempt to eliminate a dominant fixed cul de sac, the corresponding new cul de sac was entered pell mell.

The subjects often expressed surprise upon finding themselves thus thrown automatically into a cul de sac and sometimes even insinuated that they thought the experimenter had changed the pattern, by throwing in an extra cul de sac at this point to trick them. In turning into the new cul de sac the subject evidently thought he was turning into that section of the true pathway into which this turn naturally led before the avoiding movement was interpolated. No doubt the less automatic behavior of the animal, in the instance above mentioned, was due to curiosity and other such factors which might well operate to cause indecision and delay in the case of the animal, but which would be practically excluded from the stylus maze situation where all visual cues are ruled out.

It may be noted in passing that intra-pattern transfer might be an aid rather than a hindrance in cul de sac elimination under certain conditions. A maze could doubtless be constructed with the culs de sac so arranged that the interpolation of a movement in avoiding a given cul de sac would lead automatically to the avoidance of a second one also, located further along in the maze pattern, instead of leading directly to the entering of a new one as happened to be the

[1] *Op. cit.*, Carr.

case in the maze here employed. Whether the transfer is positive or negative in character, or whether or not it will be present at all depends primarily upon the specific arrangement of culs de sac, and especially of those which come to be most persistently entered. In general this phenomenon of transfer emphasizes the intimate relation between the individual movements and the total series in the integration of a complex motor habit.

IV. *An Analysis of the So-called Visual Imagery Control.*—At every point we have observed a marked contrast between the word reaction and motor methods of learning. The specific behavior of the subjects in attacking the problem; the relative variability of culs de sac at various parts of the maze pattern; the presence or absence of intra-pattern interference; the character of the reproduction graphs—in all these comparisons the two methods have been found to be characteristically different. The visual imagery method, on the other hand, seems to offer no typical differentia by which to set this mode of control over against the other two methods. It seems to call out no uniform type of behavior.

An examination of the quantitative data for this group shows it to be an intermediate and overlapping one throughout. Some of the individual records are like those of the word reaction group and others like those of the motor group, while the remainder are of a mixed type. In spite of the fact that the subjects reported that they learned primarily by following a mental image of the maze, one can hardly forbear raising the question as to the validity of this report because of internal evidence in the data indicating the wide use of the other two methods by these same subjects.

For example, of the 18 subjects of this group, 5 gave a typical motor, 5 a typical word reaction, and the remaining 8 a mixed type of reproduction graph after learning. But we have already shown that the motor type of record (exhibit *B*, Fig. 2) is occasioned by the characteristic motor response of dragging one wall of the groove thereby causing certain culs de sac to be automatically avoided, and certain others to be entered pell mell. Must we cast aside this objective evidence

that most of the members of this group used the motor mode of attack to a large extent? Or shall we suppose that they by merely dragging the edges of their *imaginal* pattern were able to produce this apparent arm-hand motor result? Under the hypothesis of imaginal control how shall we account for the 5 pure word reaction records? Are we to suppose that imaginal control operates now as if it were a motor control and again as if it were a word reaction control?

When we examine the records of this group for intra-pattern interference we find a similar lack of uniformity. It is present in approximately 2/3 of the cases and wholly absent in the remainder. But we have shown this phenomenon to be a definite transfer of a fixed set of arm-hand muscular movements from an early to a later stage of mastery. Here again is objective evidence of more or less motor control in spite of a report that imagery was used primarily. And again a minority of the group register pure word reaction type in that this interference factor is entirely absent. The same emphasis upon certain culs de sac that become persistent; the carrying over of the arm-hand motor habit illustrated in Table V. as occurring in connection with the motor method—in fact if we were classifying the members of this group on the basis of their objective records alone 2/3 of them would be included in the motor group and the remainder in the word reaction group.

The results become entirely intelligible if we suppose the visual imagery group to be made up of some who employed primarily the word reaction method, others who used mainly the motor method and a remainder who used both methods in conjunction in mastering different parts of the maze pattern. The evidence is clear that these methods were used to some extent at any rate, although the possibility that a visual imagery control may also have been operating is not, of course, ruled out. Perhaps we may at least say that if imagery was relied upon it could not have been a factor of much consequence since it did not occasion a typical response for this group, being largely overridden by word reaction and motor factors which were simultaneously operating.

Such an interpretation of the data, which is offered merely as suggestive, may seem somewhat arbitrary in view of the fact that 30 per cent. of the total number of subjects used reported primarily a visual control. However, it must be remembered that these subjects were unable to give any specific reactions growing out of the use of the image. After stating that they had relied upon imagery primarily, they began forthwith to describe the methods which they had checked as *secondary* on the questionnaire, when the experimenter was trying to find out precisely how they made use of the image. For in no case did any subject of this group even claim to have depended entirely upon visual imagery, and in a few cases both the other methods had been checked by the subject as secondary.

It is highly significant also, from this point of view, that the speedy learners of this group gave usually the word reaction method as secondary, while those requiring a large number of trials checked the motor as secondary. These subjects, moreover, had no trouble in describing the secondary methods used, although unable to give any adequate account of the *modus operandi* of the visual imagery control which they claimed to employ in the main. In this connection it ought to be remembered that the subject did not have a visual experience of the maze previous to learning it, and hence any visual imagery of the maze would involve a translation of tactual and kinesthetic experience over into the visual modality.

Since every member of the visual imagery group checked either word reaction or motor methods as secondary modes of attack, and could give no account of the operation of the visual imagery mode in the learning process, it is just possible that the former rather than the latter may have been the all important factor. The question of the sincerity of the subjects in reporting imagery, or that concerning whether or not the subjects of this group had certain experiences during the learning process which they designated as visual images, is entirely irrelevant so far as the present discussion is concerned. We are here attempting to analyze the various

types of *response* that may occur in a stylus maze situation, in order to determine the specific mechanism involved in each type, and are not concerned with the subjective experience of the subject.

It is also possible that ocular movements, rhythmic movements of the head, foot, or other member of the body, including the diaphragm, may have served as cues in learning. It may be that some of those reporting visual imagery merely meant that they were thinking of the spatial pattern of the maze, which suggests implicit word reactions and not necessarily images. An eye muscle control, involving a rhythmic adjustment of the ocular muscles, may have been confused by others with visual imagery. Such a control, as well as those based upon rhythmic movements of various parts of the body, might conceivably give a result somewhat similar to the more usual arm-hand motor control. The operation of factors such as these in some cases, and of word reaction and motor factors in other cases, suggest at least a possible explanation for the mixed character of the so-called visual imagery group.

It is clearly evident that the subjects composing this group did not all use the same mode of attack, inasmuch as the type of response indicated in the objective data proved to be quite opposite in character in many cases as we have seen. Only a part of the group could possibly be included, therefore, under the term visual imagery control, and since this latter was indescribable by the subjects themselves, and did not show itself in a definite type of response objectively, no clear case of its actual occurrence at all can be made out. While the possibility of a visual imagery factor in controlling the direction of movement at various points in the maze is not excluded by the data, the latter strongly suggests that all responses made in the stylus maze situation are either verbalizations, arm-hand motor adjustments, or perhaps ocular altitudes and rhythmic movements of some member of the body.

V. *Comparison Between Learning Record on the Maze and Intelligence Test Scores.*—Of the total of 60 subjects used in

the present experiment, 40 were students in Columbia College for whom it was possible to obtain the scores made on the Thorndike Intelligence Examination regularly given to freshmen. The Army Alpha intelligence test was also given to this same group of men. A correlation between speed in mastering the maze, in terms of the number of trials required, and both the Alpha and Thorndike test scores was thus made possible.

These two correlations, together with a third between the Alpha and Thorndike test scores themselves of the same group, are presented in Table VII. The latter correlation is quite high but is of no special interest in this connection. That between the Alpha and maze scores is also fairly high and the probable error relatively small. In the case of upper classmen the Thorndike Examination had been taken two or three years previously and these old scores were necessarily used. In a few cases at least it appeared very doubtful whether these old scores represented adequately the present performance ability of the subject. Notwithstanding this fact, a significant positive correlation was found between the maze and Thorndike test scores.

TABLE VII

CORRELATION BETWEEN SPEED IN LEARNING THE MAZE AND INTELLIGENCE SCORES

| Number of Subjects | Maze-Alpha | P.E. | Maze-Thorndike | P.E. | Alpha-Thorndike | P.E. |
|---|---|---|---|---|---|---|
| 40 | .37 | .091 | .30 | .097 | .59 | .068 |

These same 40 subjects were classified into three groups according to the mode of attack employed in learning the maze, and the average scores for each group in maze-learning and in the Alpha and Thorndike tests were computed. These group scores are given in Table VIII. There is a difference of more than 11 per cent. in both the Alpha and Thorndike score between the word reaction group on the one hand and the motor group on the other, in favor of the former group. The visual imagery group stands as usual about midway between the other two.

TABLE VIII

RELATION BETWEEN MODE OF ATTACK AND INTELLIGENCE SCORE RANK

| Mode of Attack | Number of Subjects | Trials to Learn Maze | Alpha Score | Thorndike Score |
|---|---|---|---|---|
| Word Reaction..... | 18 | 32.2 | 182.0 | 89.0 |
| Visual Imagery..... | 12 | 67.9 | 170.0 | 86.7 |
| Motor Reaction..... | 10 | 128.1 | 164.0 | 79.4 |

While the range of difference between the groups may seem to be small in terms of Alpha and Thorndike scores, it must be remembered that we are dealing with a select assemblage of individuals throughout, and consequently the range of variability in either set of intelligence test scores would naturally be relatively small. In fact the highest Alpha score made by any of the 40 subjects was only 14 per cent. higher than the lowest score of the group, while the highest Thorndike score was but 19 per cent. higher than the lowest. In view of these figures it seems quite significant that the average score, either Alpha or Thorndike, made by the word reaction group is over 11 per cent. higher than the average score, in either case, of the motor reaction group. It indicates that there is a marked tendency for those subjects making a high Alpha or Thorndike score to also 'hit upon' the word reaction method as a short cut in learning the maze. A low score, on the other hand, evidently means a greater likelihood that the subject will fail to make a short cut adjustment in mastering the situation, following the line of least resistance by sticking to the more primitive and wasteful motor method throughout. Perhaps we should expect that those who rank high in a test of the language type, such as the Alpha and Thorndike tests, should also be more likely to hit upon and utilize the same mechanism of verbalization in other situations such as the maze, since both would depend largely upon the strength and facility of the laryngeal habits of the individual.

From the purely theoretical point of view, a motor situation such as the stylus maze offers much that is ideal in the way of an intelligence test, if intelligence be defined func-

tionally as the capacity of the organism to make speedy and adequate adjustments to new situations. The *repertoire* of types of response seems to include the entire range from verbalization on the one hand to gross motor on the other, whereas the ordinary intelligence test is limited almost entirely to the language mechanism, and hence measures a smaller cross section of one's performance ability at a given moment.

This difference in the range of types of response evoked is reflected very markedly in the range of individual variation which obtains between maze scores on the one hand and the intelligence test scores on the other. Thus, within this group of 40 subjects, the number of trials required to learn ranged from 16 to 195 trials. The individual ranking lowest required 12.2 times as many trials as the one ranking highest. But we have noticed that the difference between the highest and lowest Alpha score of the same group was only 0.14, and that between the lowest and highest Thorndike score was only 0.19. The ability of a test to evoke a wide differential of response in the individual, and therefore between various individuals of a group, is a matter of great importance if the indices obtained from its use are to indicate significant differences between the individuals measured. Evidently the stylus maze fulfills this condition much better than the usual intelligence test, although this comparison must not be interpreted as an attempt to supplant the latter by the former.

## Summary of Results

1. In learning the stylus maze under the rigid technique here employed, less than 30 per cent. reported the typical motor mode of attack, while more than 40 per cent. depended primarily upon either explicit or implicit verbalization.

2. The word reaction method proved to be by far the most economical employed, requiring on the average less than 1/4 as many trials for complete mastery as the motor reaction method, and approximately 1/2 as many trials as the so-called visual imagery method.

3. The tendency under motor control is to drag one wall of the groove until a cul de sac is entered, the few culs de sac

so located as to be frequently entered in this manner becoming extremely difficult to eliminate in comparison with the other culs de sac of the maze. This is indicated by the extreme variation in difficulty between culs de sac located at various points in the pattern, in the case of the motor reaction group, in comparison with the slight variation which characterized the word reaction group.

4. A second factor operating in motor control to disturb and prolong the learning process was the wide occurrence of the negative form of what has been termed *intra-pattern* or *intra-habit* transfer. It involves the carrying over intact of a relatively fixed reaction pattern from an earlier to a later stage of mastery, and is associated with the elimination of such dominant culs de sac as have become fixated under the conditions enumerated in the preceding paragraph.

5. In attempting to reproduce, without vision, the pattern of the true pathway after having mastered the maze, two sharply contrasting types of records were produced, as indicated in exhibits *A* and *B* of Fig. 2. The word reaction type is characterized by general proportion and neatness and by angularity of turns, the motor reaction type, on the other hand, by a disproportionate sprawling general pattern, and absence of angular turns.

6. No typical form of response, either in learning the maze or in the graphic reproduction of the pathway, occurred in the case of the group reporting a visual imagery control. Internal evidence in the data suggest the possibility that this group was composed of some who used the word reaction method, others who used the motor method, and a remainder who may have used both methods in conjunction at different parts of the maze pattern. Ocular attitudes and rhythmic movements of the head, foot, diaphragm or other parts of the body may also have served as short cut methods in some cases.

7. A significant positive correlation was found between the maze learning records of 40 subjects and their Alpha and Thorndike test scores. Furthermore, the average score for the word reaction group, in the case of both the Alpha and

the Thorndike test, was over 11 per cent. higher than that of the motor reaction group. This indicates that those scoring high in these tests are also those most likely to 'hit upon' a short cut method in mastering the stylus maze situation. The correlation between maze score and intelligence test scores is apparently a function of the mode of attack employed in learning the maze.

# STUDIES RELATING TO THE PROBLEM OF BINOCULAR SUMMATION

BY DONALD A. LAIRD

## I. Introduction

The semi-decussation of fibers in the retino-cerebral pathways of man has important implications for psychological theory. When both eyes are stimulated simultaneously under the neural conditions prevailing in a semi-decussation there is a double stimulation of each hemisphere. One would be led to expect differences in the responses to equal binocular and monocular stimuli under such conditions.

## II. Historical

An increase in the intensity of binocular over monocular sensations has been reported by Fechner (6), Helmholtz (7), Valerius (16), and Houston (9). Fechner and Helmholtz merely report that a binocularly viewed surface appears brighter than the same surface viewed monocularly. Valerius states that the difference in brightness amounts to about 1/15 of the original monocular sensation. Houston accepts as unequivocally established the binocular summation of stimuli and attributes it to the luminosity features, due to a single photochemical process.

Aubert (3) is convinced of the existence of binocular summation but hastens to add that it quite likely does not occur in an amount to be noticeable with illumination greater than that of white paper in daylight. Piper (13) also modified the statement of his experiments to indicate that summation is noticeable only with dim illumination. McDougall (12) and Roelofs and Zeeman (14) also report a failure to find evidences of summation in bright illumination. Lohman found a binocular summation of threshold stimuli when taking descending measures (10). In discriminating bright-

nesses Dawson found the threshold for grey was increased by about half when only one eye was used (5).

In contrast with these Hering (8) reports he is unable to find any difference between binocular and monocular stimuli. Sherrington (15) makes a similar report for brightness while Cobb (4) found no evidence of summation in form discrimination.

The most recent work is that of Allen (1, 2). He found that the critical flicker frequency of one eye varied with the stimulation of the unused eye. This reflex effect, as Allen terms it, varied in magnitude with the colors used to fatigue the unused eye. Thus when the left eye was continuously stimulated by violet the critical flicker frequency of the right eye was different from the same threshold when the left eye was stimulated with another wave-length.

## III. Experimental

*Stimulus Carrier.*—This comprised a light-proof compartment 6.5 cm. high, 13.0 cm. wide, and 10.0 cm. long. It is shown in Fig. 1. It was divided into two compartments by a removable partition fitting into grooves ($g^3$). The bridge of the subject's nose rested in the notch at ($n$). Two sliding cards (eyepiece cards, *es*) provided with 1 mm. openings ($p$) as artificial pupils were used to limit the range of vision. At the opposite end of the stimulus carrier are located two other adjustable cards, the objective slides (*os*). A shelf ($s$) is also provided at this end of the carrier for supporting the color stimuli. All of the slides were provided with reference marks ($r$) by aid of which the positions could be kept constant by reference to the meter scales (*ms*). The wood box and the slides were finished in a dead black.

*Stimuli or Objective Slides.*—These were pierced with a pin at their vertical center. In addition to this pinhole larger circular openings were cut with a punch; these were the openings through which the light stimuli were admitted. Their diameter was 4 mm.; their farthest point from the pinhole was 7 mm., bringing their image within the macula of the average eye.

Three of these objective slides were prepared as shown in Fig. 2. Slide *B* was used in all phases of the experiment. In determining the sensitivity thresholds the partition was removed, the pinhole of objective *B* was brought to the center of the large compartment, and the eyepieces adjusted so that both eyes could see the two large discs balanced to the

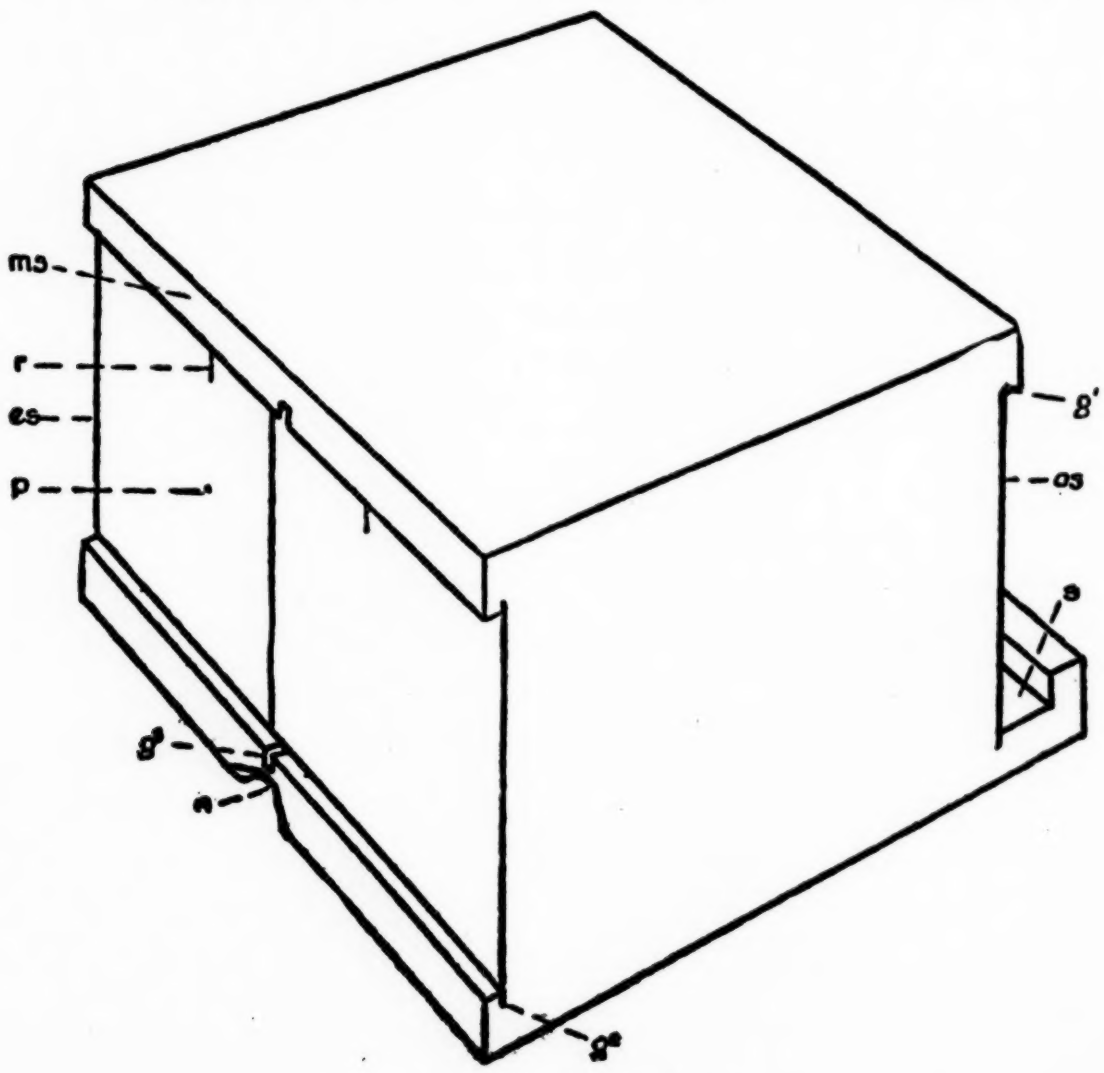



FIG. 1. The stimulus carrier

right and left of the pinhole in the objective. This was the arrangement in determining the binocular sensitivity threshold. In obtaining the sensitivity threshold for the left eye the eyepiece in front of the right was moved slightly so that the artificial pupil was out of the line of regard. In obtaining the sensitivity threshold for the right eye the artificial pupil in front of the left was moved out of line.

In the first determinations of the *RL* only one of the objective openings was covered with the color slide. Later data were obtained by having an objective with only one opening for these same determinations.

In obtaining the threshold of discrimination one window of objective *B* was covered with a slide of known color value and the color slides over the other window varied until the two openings were pronounced equal.

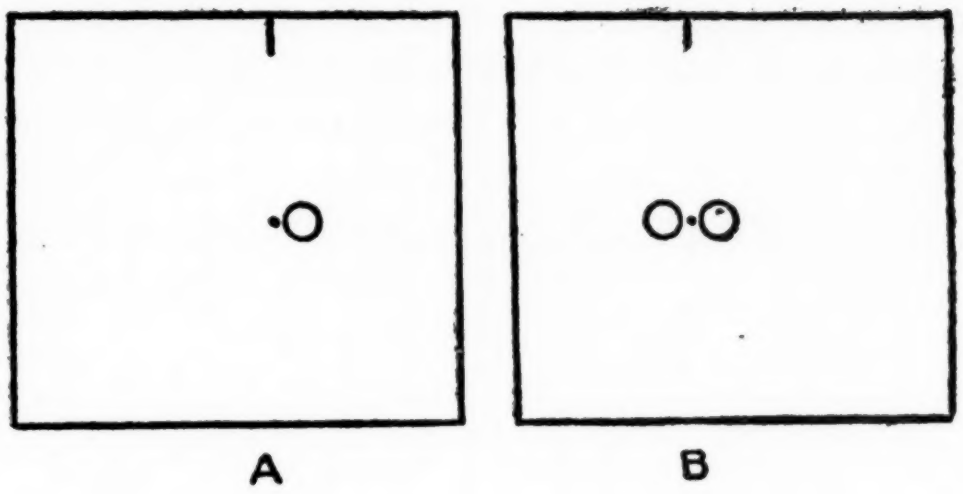



FIG. 2. The objective slides

In the second series of experiments two objective cards were used. Objective *B* was always used, and in the right compartment, the partition being reinserted.

Fig. 3 shows the optics of the combination of slide *B* and *A*. The heavy solid lines represent the inner walls of the stimulus carrier in longitudinal section. At the observer's end of the carrier the artificial pupils are represented by breaks in the lines. The lines which pass through these openings represent the course of light from the objectives to the retinæ.

The light from the pinholes in the objectives falls on the foveæ. The rays from windows *b* and *b''* fall on corresponding points of the two retinæ, while the rays from opening *a* are used as the standard or master stimulus value. What the observer sees when the proper juxtaposition of the retinal images has been secured by manipulating the slides in their grooves is shown in Fig. 4. The appearance is of two discs,

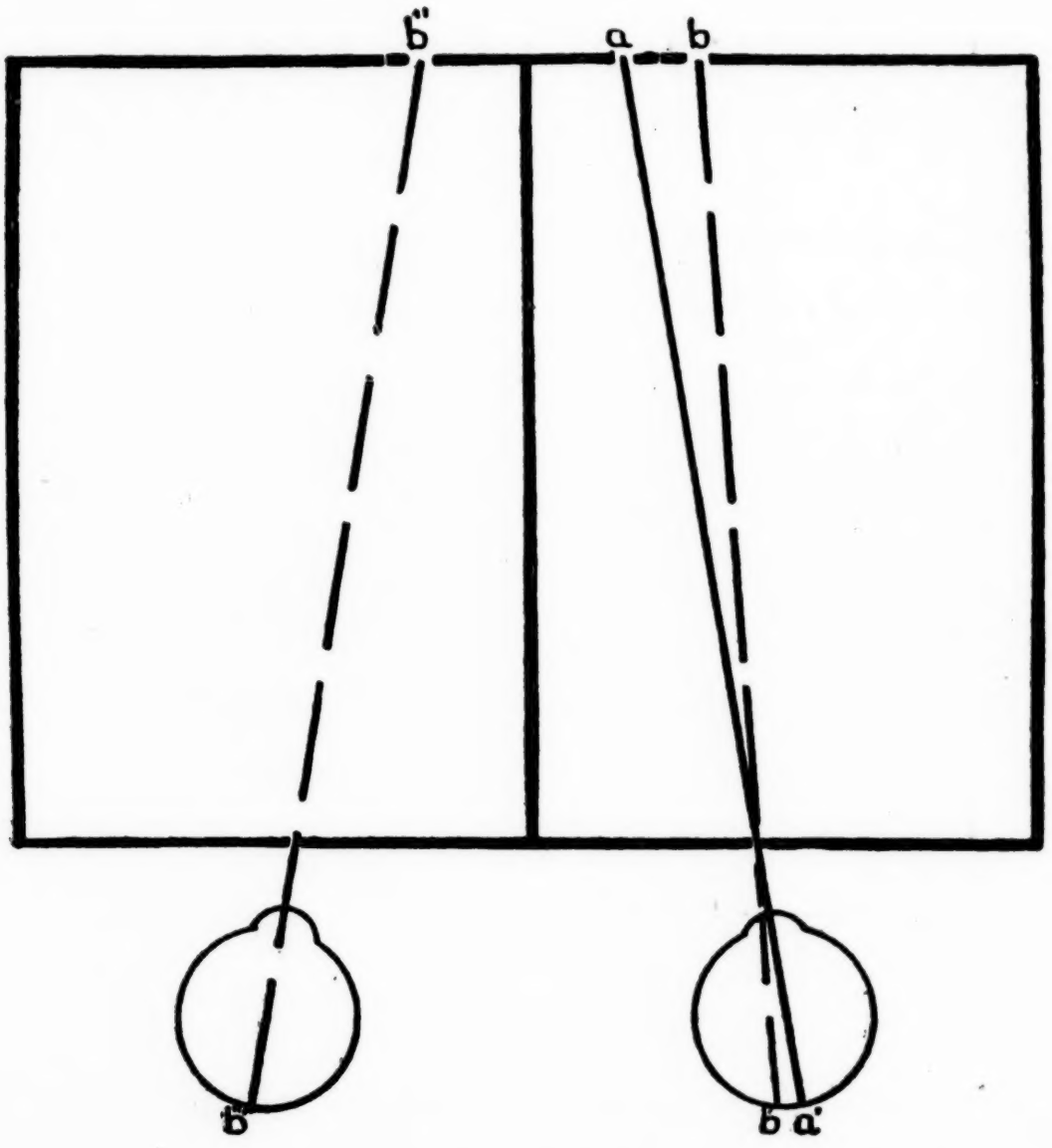



FIG. 3

the one to the right, however, is *a fusion of the stimulation of the separate retinæ*.

A color slide of, say, 20 color units (c.u.) is placed over window *a*. Smaller c.u. are placed over windows *b* and *b''* and shifted until the binocular image (that to the right) appears equal to the monocular image.

In the arrangement of objectives just described the left

eye is stimulated upon receptors that are not supposed to cross. This will be termed temporal stimulation. When objectives *B* and *C* are used in combination the summating image falls upon the crossed fibers of the left eye, or what will be termed nasal summation. In the latter instance the master monocular stimulus to be matched is placed over window *b*.

A screen of white cardboard was erected around the carrier so that the subjects' vision of what was happening at the objective slides was cut off.

FIG. 4

*The stimuli.*—The Lovibond tintometer color slides were used (11). Spectroscopic stimuli would have been preferable but the color slides were readily accessible and are calibrated in visual units. This latter characteristic makes it possible to say whether or not the retino-cerebral mechanism summates visual units.

The stimuli were illuminated by light from a small stereoptican reflected from white cardboard 50 cm. from the stimulus carrier. All observations were carried out in a light proof room.

*Retinal Adaptation.*—The subjects spent ten minutes in a constant position in the experimental room as a preëxposure interval. In the photopic observations the subject placed his eyes in position in front of the artificial pupils and retained this position for five additional minutes before readings were commenced.

In the scotopic observations after ten minutes of the preexposure interval had elapsed the subject's head and eyes were covered with a black felt hood. After ten more minutes under this hood and with the hood still in position he was placed in front of the artificial pupils and the open end of the hood fastened around the stimulus carrier by rubber

bands. Observations began immediately. For these observations the surface of the eyepiece next to the observer was covered with the No. 48 of the Hering greys.

## IV. Presentation of Data

### 1. (*a*) *Sensitivity.*

It is quite apparent from Table I. that there is a keenness in binocular photopic vision that is not reached by monocular vision under the same conditions. A measure of this increased binocular sensitivity may be had by computing the per cent. of reduction in the stimulus by the following formula:

$$\text{P. ct. reduction} = 100\,\frac{\left(\frac{RL_{\text{left}} + RL_{\text{right}}}{2}\right) - RL_{\text{binocular}}}{\left(\frac{RL_{\text{left}} + RL_{\text{right}}}{2}\right)}.$$

Table I

Thresholds for Sensitivity to Red; Photopic Vision
(In Lovibond Color Units)

| Subject | | Left | Right | Binocular |
|---|---|---|---|---|
| C.K. | Mn. | .20 | .20 | .16 |
| | S.D. | .016 | .014 | .013 |
| W.S. | Mn. | .67 | .71 | .39 |
| | S.D. | .016 | .017 | .013 |
| W.A. | Mn. | .45 | .40 | .35 |
| | S.D. | .029 | .020 | .018 |
| R.H. | Mn. | .51 | .57 | .40 |
| | S.D. | .026 | .031 | .027 |
| T.K. | Mn. | .73 | .78 | .47 |
| | S.D. | .032 | .037 | .029 |
| A.H. | Mn. | .32 | .38 | .24 |
| | S.D. | .024 | .038 | .023 |
| T.S. | Mn. | .80 | .87 | .53 |
| | S.D. | .028 | .023 | .036 |
| H.C. | Mn. | .41 | .37 | .31 |
| | S.D. | .025 | .025 | .035 |
| I.S. | Mn. | .82 | .71 | .53 |
| | S.D. | .030 | .029 | .021 |

The use of this formula with the data of Table I. gives an average per cent. of reduction of 31.3, S.D. 7.4. The per cent. of reduction ranges from 20.0 to 43.5. If summation existed unimpaired the per cent. reduction would be 50; of the data obtained only one approaches this with a reduction

of 43.5 per cent. The present data can be looked upon only as giving a remote approximation to summation.

## TABLE II

THRESHOLDS FOR SENSITIVITY TO RED; SCOTOPIC VISION
(In Lovibond Color Units)

| Subject | | Left | Right | Binocular |
|---|---|---|---|---|
| C.K. | Mn. | .19 | .19 | .18 |
| | S.D. | .021 | .011 | .014 |
| W.S. | Mn. | .45 | .50 | .35 |
| | S.D. | .013 | .018 | .013 |
| W.A. | Mn. | .31 | .28 | .21 |
| | S.D. | .033 | .022 | .020 |
| R.H. | Mn. | .40 | .41 | .36 |
| | S.D. | .025 | .022 | .027 |
| T.K. | Mn. | .56 | .61 | .42 |
| | S.D. | .028 | .031 | .022 |
| A.H. | Mn. | .26 | .25 | .22 |
| | S.D. | .026 | .023 | .021 |
| T.S. | Mn. | .61 | .63 | .42 |
| | S.D. | .027 | .027 | .023 |
| H.C. | Mn. | .32 | .31 | .25 |
| | S.D. | .035 | .026 | .024 |
| I.S. | Mn. | .67 | .50 | .40 |
| | S.D. | .039 | .022 | .030 |

In Table II. the corresponding thresholds in the case of scotopic vision are given. The average per cent. reduction of these is 21.1, with a standard deviation of 9.3. Summation is approximated in these data even less than under light adapted vision.

### (*b*) *Discrimination*

Table III. gives these data for photopic vision, Table IV. for scotopic vision. The binocular reduction of the former averages 23.5, S.D. 11.2 per cent.; the latter has an average reduction of 28.0, S.D. 16.9 per cent. Summation is again approximated only very loosely.

### (*c*) *Discussion*

The failure of these data to demonstrate summation does not necessarily preclude summation. There is a possibility that they are rendered invalid by the very action of summation, assuming that it does exist. In the determinations of

## TABLE III

THRESHOLDS FOR DISCRIMINATION OF RED; PHOTOPIC VISION
(In Lovibond Color Units)

| Subject | | Left | Right | Binocular |
|---|---|---|---|---|
| C.K. | Mn. | .18 | .21 | .19 |
| | S.D. | .016 | .019 | .011 |
| W.S. | Mn. | .87 | .53 | .45 |
| | S.D. | .022 | .014 | .025 |
| W.A. | Mn. | .60 | .52 | .37 |
| | S.D. | .032 | .035 | .024 |
| R.H. | Mn. | .63 | .70 | .40 |
| | S.D. | .027 | .026 | .024 |
| T.K. | Mn. | .65 | .68 | .47 |
| | S.D. | .026 | .031 | .030 |
| A.H. | Mn. | .36 | .34 | .30 |
| | S.D. | .028 | .024 | .024 |
| T.S. | Mn. | .53 | .46 | .43 |
| | S.D. | .028 | .024 | .027 |
| H.C. | Mn. | .74 | .82 | .53 |
| | S.D. | .034 | .027 | .030 |
| I.S. | Mn. | .72 | .62 | .54 |
| | S.D. | .038 | .032 | .032 |

## TABLE IV

THRESHOLDS FOR DISCRIMINATION OF RED; SCOTOPIC VISION
(In Lovibond Color Units)

| Subject | | Left | Right | Binocular |
|---|---|---|---|---|
| C.K. | Mn. | .16 | .16 | .16 |
| | S.D. | .014 | .010 | .012 |
| W.S. | Mn. | .53 | .41 | .37 |
| | S.D. | .020 | .022 | .020 |
| W.A. | Mn. | .41 | .38 | .28 |
| | S.D. | .025 | .027 | .027 |
| R.H. | Mn. | .56 | .65 | .29 |
| | S.D. | .022 | .026 | .020 |
| T.K. | Mn. | .52 | .57 | .45 |
| | S.D. | .024 | .027 | .024 |
| A.H. | Mn. | .32 | .40 | .21 |
| | S.D. | .026 | .022 | .031 |
| T.S. | Mn. | .38 | .36 | .34 |
| | S.D. | .032 | .030 | .033 |
| H.C. | Mn. | .80 | .74 | .40 |
| | S.D. | .023 | .032 | .025 |
| I.S. | Mn. | .64 | .51 | .33 |
| | S.D. | .010 | .031 | .031 |

the thresholds of discrimination, for instance, two openings were used in the objective slide. Behind one of these was placed the color slide of 5 c.u. that was used as the standard.

When monocular observations were taken only one eye saw this comparison standard. When the binocular thresholds were obtained both eyes were stimulated by this same slide. Assuming that summation does exist it will be readily seen that this procedure results in the standard varying from the monocular to the binocular observations. The monocular records give the smallest perceptible difference on a basis of a standard of 5 c.u., while the binocular data so far cited in reality give the differential threshold for 7 or perhaps 10 c.u. and not for 5 c.u. The same considerations apply to the data given so far for sensitivity since two openings were also used in the objective. If summation does exist it invalidates these measures as well as those of other observers with the exception of Piper and Allen.

TABLE V

VALID DATA FOR SUMMATIVE EFFECTS IN SENSITIVITY WITH RED AS A STIMULUS
(In Lovibond Color Units)

*Photopic Vision*

| Observer | Left | Right | Binocular |
|---|---|---|---|
| N.S.....Mn..... | .08 | .05 | .05 |
| H.R.....Mn..... | .07 | .05 | .06 |
| H.L.....Mn..... | .06 | .08 | .06 |
| L.T.....Mn..... | .06 | .03 | .03 |

*Scotopic Vision*

| Observer | Left | Right | Binocular |
|---|---|---|---|
| N.S.....Mn..... | .07 | .06 | .03 |
| H.L.....Mn..... | .09 | .10 | .04 |
| H.R.....Mn..... | .08 | .06 | .03 |
| L.T.....Mn..... | .12 | .08 | .03 |
| C.B.....Mn..... | .09 | .16 | .06 |

### (*d*) *Further Data for Sensitivity*

When records are obtained of the sensitivity thresholds with only one opening in the objective very different results are found, as will be seen from Table V. The results with the light adapted eye are little different from those previously reported, while with scotopic vision summation seems to be

reached. The average per cent. of reduction with photopic vision is 18.7 (S.D. 12.2). The corresponding figure for scotopic vision is 58.6 (S.D. 5.8).

The scotopic increase over summation may be due to an overlapping and reinforcement of attention waves in addition to summation itself. Dawson has interpreted his findings, which we have found not to be valid, as being due to this factor of attention rather than to summation. Some selective process probably functions in a selection of the stimuli to which to respond. The data for photopic vision in Table V. show a tendency for the binocular thresholds to equal that of the keener eye. This may very likely indicate some functioning similar to that observed in the microscopist who neglects the images in one eye. With scotopic vision there are no indications of a similar mechanism functioning. There is a strong possibility that this selecting, rather than a reinforcing, explains the slight binocular increases reported by previous investigators. In the instance of visual acuity it is generally agreed that the better eye predominates.

### (*e*) *Summary*

1. Summation of stimuli in sensitivity has been demonstrated in scotopic vision.

2. This has not been demonstrated for photopic vision.

3. It appears that in photopic vision the response to binocular stimuli is selective rather than summative.

4. Valid data for discriminative responses have not been secured.

## 2. (*a*) *Equating of Stimuli on Corresponding Points with a Monocular Stimulus*

The arrangement described on page 280 made possible the equating of color stimuli divided between corresponding points of the two retinæ with a color stimulus limited to only one retina. The latter stimulus has been termed the master color value. If summation of stimuli between the two eyes takes place one would expect to find a master color stimulus

of 20 c.u. matched by stimuli divided between the two retinæ which total 20 c.u.

### (*b*) *Photopic Vision*

Table VI. shows that a monocular stimulus of 20 c.u. is matched by binocularly combined slides with a combined color value ranging from 37.8 to 40.0 c.u. The master stimuli of 10 and of 1 c.u. reveal the same total failure to approximate summation.

### Table VI

Binocularly Divided Stimulation to Equal the Monocular Stimulus Indicated; for Red. Photopic Vision
(In Lovibond Color Units)

| Subject | | Monocular Stimulus Value | | |
|---|---|---|---|---|
| | | 20 c.u. | 10 c.u. | 1 c.u. |
| C.K. | Mn. | 37.7 | 18.4 | 1.7 |
| | S.D. | 1.67 | 1.09 | .193 |
| W.S. | Mn. | 37.8 | 20.5 | 1.9 |
| | S.D. | 3.35 | 2.67 | .28 |
| W.A. | Mn. | 39.2 | 19.1 | 1.9 |
| | S.D. | 2.61 | 2.62 | .87 |
| R.H. | Mn. | 39.6 | 20.0 | 1.9 |
| | S.D. | 2.28 | 1.44 | .51 |
| T.K. | Mn. | 40.0 | 18.5 | 2.0 |
| | S.D. | 2.69 | 1.65 | .23 |
| A.H. | Mn. | 38.8 | 19.5 | 1.93 |
| | S.D. | 2.78 | 1.15 | .65 |
| T.S. | Mn. | 38.8 | 19.9 | 1.9 |
| | S.D. | 2.63 | 1.62 | .22 |
| H.C. | Mn. | 39.7 | 19.7 | 1.9 |
| | S.D. | 2.06 | 1.64 | .24 |
| I.S. | Mn. | 39.7 | 20.2 | 2.0 |
| | S.D. | 2.33 | 2.08 | .61 |

### (*c*) *Scotopic Vision*

The data of Table VII. reveal that the adaptation change has altered the summative effects markedly. With a master stimulus of 20 c.u. a total stimulation of only from 19.5 to 21.7 c.u. divided between the two retinæ is needed to produce equality. Similarily with the weaker master stimuli summation is found. Essentially the same results as reported in Tables VI. and VII. were found with the combination of slides that is termed temporal, and with blue stimuli as well as the red.

## TABLE VII

BINOCULARLY DIVIDED STIMULATION TO EQUAL THE MONOCULAR STIMULUS INDICATED; FOR RED. SCOTOPIC VISION
(In Lovibond Color Units)

| Subject | | Monocular Stimulus Value | | |
|---|---|---|---|---|
| | | 20 c.u. | 10 c.u. | 1 c.u. |
| C.K. | Mn. | 19.7 | 10.5 | .9 |
| | S.D. | 1.09 | 1.48 | .092 |
| W.S. | Mn. | 21.7 | 11.2 | 1.0 |
| | S.D. | 1.63 | .89 | .194 |
| W.A. | Mn. | 20.9 | 9.3 | 1.0 |
| | S.D. | 2.62 | .96 | .136 |
| R.H. | Mn. | 19.8 | 10.4 | 1.0 |
| | S.D. | 1.72 | .802 | .118 |
| T.K. | Mn. | 20.8 | 9.8 | 1.0 |
| | S.D. | 2.36 | 1.31 | .086 |
| A.H. | Mn. | 19.5 | 9.3 | 1.0 |
| | S.D. | 2.24 | 1.49 | .64 |
| T.S. | Mn. | 20.4 | 10.1 | 1.0 |
| | S.D. | 2.01 | 1.05 | .13 |
| H.C. | Mn. | 20.1 | 10.5 | 1.0 |
| | S.D. | 2.24 | 1.14 | .46 |
| I.S. | Mn. | 21.1 | 10.4 | 1.1 |
| | S.D. | 2.09 | 1.13 | .07 |

### (*d*) *Summary*

1. Summation under the conditions detailed has been demonstrated in scotopic vision.

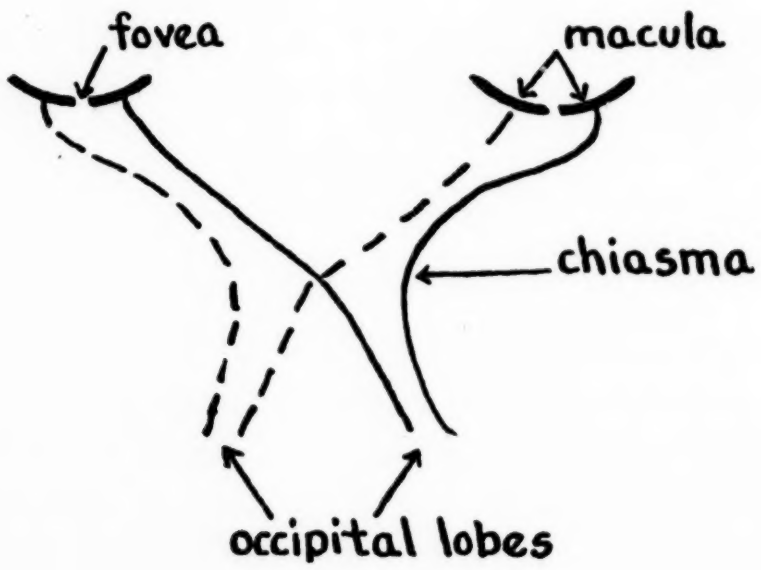



FIG. 5

2. This summative effect is totally absent in photopic vision.

3. These two statements are not altered when either red or blue stimuli are used.

4. There are no indications of individual differences in this summation of binocular visual stimuli.

## V. Theoretical

The commonly accepted arrangement of retino-cerebral fibers is diagrammed in Fig. 5. In this only the maculæ have been represented, and these in halves as they are considered to be connected with the hemispheres.

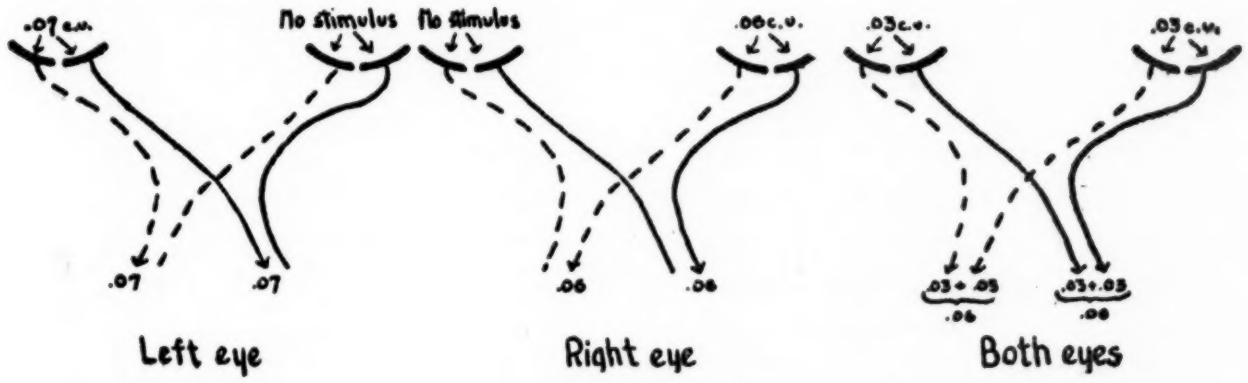



Fig. 6

The increase in binocular over monocular sensitivity in scotopic vision is well accounted for by this diagram, as is shown in Fig. 6 where the data for the scotopic sensitivity of

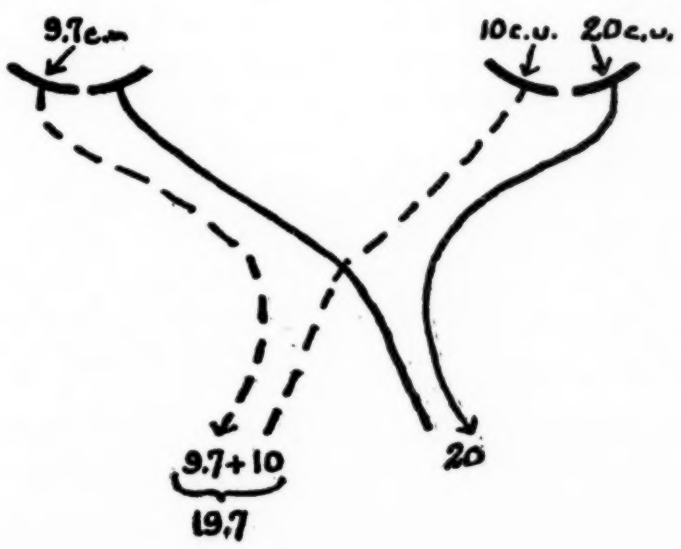



Fig. 7

observer N.S. (Table V.) have been used. The cortical stimulation, which is probably the crucial stimulation for these responses, seems to be reached when either the right or

left tract is stimulated by a color value of .06 to .07 c.u. The binocular combination is represented in the right portion of Fig. 6 which shows how binocular vision makes possible a lower retinal stimulus value while still producing an effective cortical stimulation.

Using the data obtained from subject C.K. (Table VII.) for Fig. 7 it is shown how the neurological schema explains the findings in the second experiments.

The failure to obtain an adequate approximation to summation in photopic vision can be explained only on the basis of a selective response, in which the response seems to be limited to one eye, the other being inhibited in some manner.

## References Cited


1. Allen, F. *Jour. of the Optical Society of Amer.*, 1923, Vol. 7, pp. 583–626.
2. Allen, F. *Jour. of the Optical Society of Amer.*, 1923, Vol. 7, pp. 913–942.
3. Aubert. Physiologische Optik, 1865, pp. 500.
4. Cobb, P. W. *Jour. Exptl. Psychol.*, 1922, Vol. 5, pp. 227–246.
5. Dawson, S. *Brit. Jour. Psychol.*, 1913, Vol. 6, 78 ff.
6. Fechner, G. T. Abhandl. d. Sächs. Ges. d. Wiss., 1861, Vol. 7, 423 ff.
7. Helmholtz, H. Handbuch des Physiologische Optiks, 1866.
8. Hering, E. Handbuch d. Physiol. d. Sinnesorganne. (Cited by Piper.)
9. Houston, R. A. *Proc. Royal Society*, 1916, Vol. 92, pp. 424–432.
10. Lohman, W. *Arch. f. Augenheilk.*, 1915, Vol. 74, pp. 110–116.
11. Lovibond, J. W. Measurement of Light and Color Sensations. London, Gill & Sons. No date.
12. McDougall, Wm. *Brain*, 1911, Vol. 33, pp. 371–388.
13. Piper, H. *Zeit. f. Psychol. u. Physiol. d. Sinnesorganne*, 1903, Vol. 32, pp. 161–176.
14. Roelofs, C. O., and Zeeman, W. P. C. *Arch. f. Opthalmol.*, 1914, Vol. 88, pp. 1–27.
15. Sherrington, C. S. *Brit. Jour. Psychol.*, 1904, Vol. 1, pp. 26–52.
16. Valerius. *Ann. d. Physic u. Chemie*, 1873. (Cited by McDougall.)

# THE EFFECT OF ENDOCRINE FEEDING UPON THE LEARNING PERFORMANCE OF WHITE RATS

BY W. E. BLATZ AND W. T. HERON[1]

There has recently been a flood of pseudoscientific literature in many of the associated sciences concerning the possible relationship between the ductless glands and personality, disease, intelligence, insanity, sex function, and genius—ad nauseam. In the field of physiology, so talented a writer as G. N. Stewart remarks upon the lack of definite, corroborative data within the scope of this topic (11). In psychology this field is barren. No data whatever are at hand other than highly speculative conjectures.

The following study was undertaken to introduce into experimental psychology a method of studying this fruitful field in a scientific manner. If it but stimulates further investigation in this aspect of psychophysical research it will have fulfilled its purpose, aside from the results of the experiment which the authors acknowledge are far from being unequivocal.

The specific purpose of this investigation was to discover how a disturbance of the 'endocrine balance' of the body would affect the learning process.

The endocrine equilibrium may be disturbed in two ways: (*a*) attempts in the direction of lessened activity of one or more components, called hypofunction, by means of extirpation, ligature, cautery, etc.; (*b*) attempts in the direction of exaggerated activity of one or more components, or hyperfunction, by means of grafting, injection, feeding, etc. It was decided to attempt by the latter method (as offering the easiest means, although by no means the most efficient) to study the result of anticipated hyperfunction of certain of the gland tissues.

[1] From the Psychological Laboratory of the University of Chicago.

Since this research was begun in December, 1921, there have appeared a series of papers by Liddell and Simpson (3, 4, 5, 6) reporting upon experiments which are here briefly reviewed.

Their problem was to study the effect of extirpation of the thyroid gland upon the intelligence of sheep, see method (*a*) above. They employed a modification of the maze problem as a measure of intelligence. They also measured activity by a pedometer arrangement and the 'muscular exertion' by an adjustable inclined plane.

They used in all 8 animals, 4 pairs of twins. After having learned the maze, the 'more intelligent' twin of each pair was operated upon. Cretinism resulted in all operated cases.

Their behavior was then studied and compared with the normal. Both normal and cretin were required to *relearn* the old maze and then a new arrangement of the maze was presented as a new *learning* problem.

We have brought their results together in the form given in Table I. The four criteria chosen by the authors are arranged in the first column. Under each of these the results of the two tests, viz., relearning and learning of second problem are arranged. Where the normal animal showed to advantage an *N* was placed. Where the thyroidectomized or cretin animal showed to advantage a *C* was placed. The last 4 columns represent the records of the respective pairs of twins.

TABLE I

| | | I | II | III | IV |
|---|---|---|---|---|---|
| *Trials* | Relearning | *C* | *N* | Equal | *C* |
| | Learning | *C* | * | *C* | *C* |
| *Errors* | Relearning | *N* | *N* | *C* | *C* |
| | Learning | *N* | * | *N* | *N* |
| *Total Steps* | Relearning | * | *N* | *N* | *N* |
| | Learning | *N* | * | *N* | *C* |
| *Time* | Relearning | *C* | *N* | Equal | *C* |
| | Learning | *N* | * | *N* | *N* |

As can be seen, the results show a tendency to the advantage of the normal animals but not unambiguously so.

* No data.

In a further investigation 4 cretins (it does not state whether these were the above animals or not) were treated by injection of thyroxin and showed a 'pronounced increase in neuromuscular activity.'

As time did not permit us to study all of the more important glands, a choice was made and two were selected,—Anterior Pituitary and Adrenal Cortex. Dried extract obtained from Armour and Co. was fed to white rats and they were then subjected to the test. A control group were fed dried brain tissue and given identical tests. It was understood that feeding fresh glands would have been better, but for many reasons this was impossible. It was felt, however, that the dried tissue was not inactive because of the concomitant changes noted in the physiological rhythms and other indications recorded below.

A brief summary of the commonly accepted functions of the above two glandular secretions may not be amiss.

The *Anterior Pituitary* appears to be closely associated with osseous growth, genital development, maintenance of muscle tonus and adiposity. Experimental hypofunction is accompanied by apathy (2, 7, 8, 9).

The *Adrenal Cortex* is still the subject of conflicting opinions. By some it is thought to be the seat of the elaboration of the secretion of the medullary portion. Schaeffer (9) states "the suggestion that the suprarenal cortex may be a seat of manufacture of the lipoids of the body and may especially be related to the formation and development of the myelin of the medulated nerve fibres is attractive. There seems to be a connection between the development of the substances formed in the cortex and those constituting the cerebral hemispheres." Wheeler and Vincent are of the opinion that the cortex is the 'actual vital portion of the adrenal gland' (12).

The acceptance or nonacceptance of the above dicta does not in any way affect the results of this paper so that further discussion is unnecessary.

The duration of the investigation was over a period of 18 months of daily observations. It may be divided chronologically into three experiments.

## Experiment I

Sixty rats, approximately 30 days old, were purchased and divided into three groups of 20 rats each as nearly alike as possible with reference to sex and size. They were appropriately marked by clipping the ears to make identification easy and accurate. They were then weighed and placed in cages, sexes being separated to prevent breeding. The weighing was repeated at intervals of one week until the experiment was completed.

One group was fed .1 gm. per rat of dried brain tissue [1] and the second group the same amount of dried ant. pituitary extract, and the third group a like amount of dried adrenal cortex. The three groups were fed daily for two weeks prior to the beginning of the learning task, and the feeding was continued throughout the experiment. During this experiment the substance to be fed was weighed in bulk for the whole group (*i.e.*, 2 gms.) and then mixed with bread and milk and administered so the whole group (20) as the first portion of their daily feeding which always followed the learning task and consisted almost exclusively of bread and milk with the occasional addition of sunflower seeds. This method of administration was modified in the later experiments as noted below.

For this experiment we employed the square maze as described and used by Warden (13). Records were kept of the Gross Time, Static Time, Net Time, Forward Errors, Backward Errors and Retracings.[2] The rats were given one trial per day on successive days.

[1] As the feeding of the dried extracts of pituitary and adrenal introduces a nutritional factor in the nature of an added protein to the diet, the group which is called the control group were fed brain tissue which is held to be physiologically inert when ingested (7, 10).

[2] To avoid ambiguity the terms employed will be defined as the authors employed them in recording results.

*Gross Time*—Time elapsing from the entrance of rat in the maze to the entrance of rat into food-box.

*Static Time*—Time during which the rat did not move forward or backward, the time spent by the rat in resting, sleeping, performing its ablutions, etc.

*Net Time*—Gross Time − Static Time = the time actually spent in exploring the maze.

*Forward Errors*—Blind alleys entered when proceeding toward food box.

It was decided to continue running a rat until it had completed three successive trials without error or retracing. Only 28 of the whole number reached this stage of mastery because of a virulent infection which caused the death of the entire group before all had reached this stage. However, 46 of the whole number accomplished at least one trial without error or retracing and this was chosen as a second criterion and called 'incomplete,' as opposed to 'complete' learning described above. Table II. shows the number of rats in each group under the two criteria.

TABLE II

| | 'Complete' | 'Incomplete' | Original Number |
|---|---|---|---|
| Control | 9 | 17 | 20 |
| Pituitary | 9 | 13 | 20 |
| Adrenal | 8 | 12 | 20 |

An examination of Table III compiled from the data of experiment 1 shows the following relations. The pituitary group has the best standing throughout the whole table except in the average net time per trial per rat and average time for last three trials, where it is inferior in rank to the control group. The adrenal group shows the poorest record in all cases except in the average number of trials necessary to attain the 'incomplete' degree of mastery, in the average static time for incomplete, and in the forward errors for complete. The control group is intermediate in all cases except the instances mentioned above.

A brief survey indicates that the pituitary group required fewer trials to reach the same degree of mastery of the maze, took relatively less time to accomplish this task and relatively fewer errors, spent less time in 'idling' in the maze and hence the actual time spent in exploring the maze is longer and since there are fewer errors, one may conjecture that this group was relatively less active and hence more thorough.

*Backward Errors*—Blind alleys entered when proceeding toward entrance door.
*Retracings*—Number of sections of the maze travelled in direction opposite to food box in 'true path.'

TABLE III

| Criteria | Complete | | | Incomplete | | |
|---|---|---|---|---|---|---|
| Group | Control | Pituitary | Adrenal | Control | Pituitary | Adrenal |
| Number of rats | 9 | 9 | 8 | 17 | 13 | 12 |
| Average number of trials per rat | 34 | 31 | 36 | 31 | 24 | 25 |
| Average time, in seconds, per rat | | | | | | |
| Gross | 4,104 | 3,188 | 4,954 | 4,184 | 3,136 | 4,332 |
| Static | 1,901 | 1,130 | 2,148 | 1,655 | 909 | 1,481 |
| Net | 2,203 | 2,058 | 2,806 | 2,529 | 2,227 | 2,851 |
| Average time, per trial, per rat | | | | | | |
| Gross | 120 | 102 | 137 | 135 | 131 | 173 |
| Static | 56 | 36 | 60 | 53 | 38 | 59 |
| Net | 64 | 66 | 77 | 82 | 93 | 114 |
| Average time of last 3 trials | | | | 28.3 | 28.9 | 30.8 |
| Average errors per rat | | | | | | |
| Forward | 69 | 59 | 63 | 64 | 52 | 74 |
| Backward | 10 | 9 | 11 | 9 | 8 | 10 |
| Retracing | 119 | 93 | 139 | 112 | 97 | 127 |
| Total | 198 | 161 | 213 | 185 | 157 | 211 |
| Average total errors per trial per rat | 5.8 | 5.0 | 6.0 | 6.0 | 5.8 | 8.0 |

The adrenal group took more trials to reach the complete criterion, spent the most time in the maze both in idling and in exploring and showed the most errors of all kinds, this perhaps accounting for the increased time.

## EXPERIMENT 2

The second experiment was designed to duplicate the first and followed it chronologically. The rats were bred in the laboratory. For the maze was substituted an inclined plane problem-box, electrically actuated. Sixty rats were again selected and prepared as above with reference to sorting, clipping, weighing, and feeding. The feeding in this case was more carefully controlled. The whole quantity of the powder was weighed and then mixed into a paste and then divided into 20 pellets. Each rat was placed into an indi-

vidual compartment after it had run in the problem box and was left there until it had eaten the pellet; then it was removed to the feeding cage and allowed to eat as much bread and milk as it desired. These rats were fed after they had been weaned and reached 30 days of age. The feeding of the extract was continued for 2 weeks before starting the learning task, and throughout the course of the experiment.

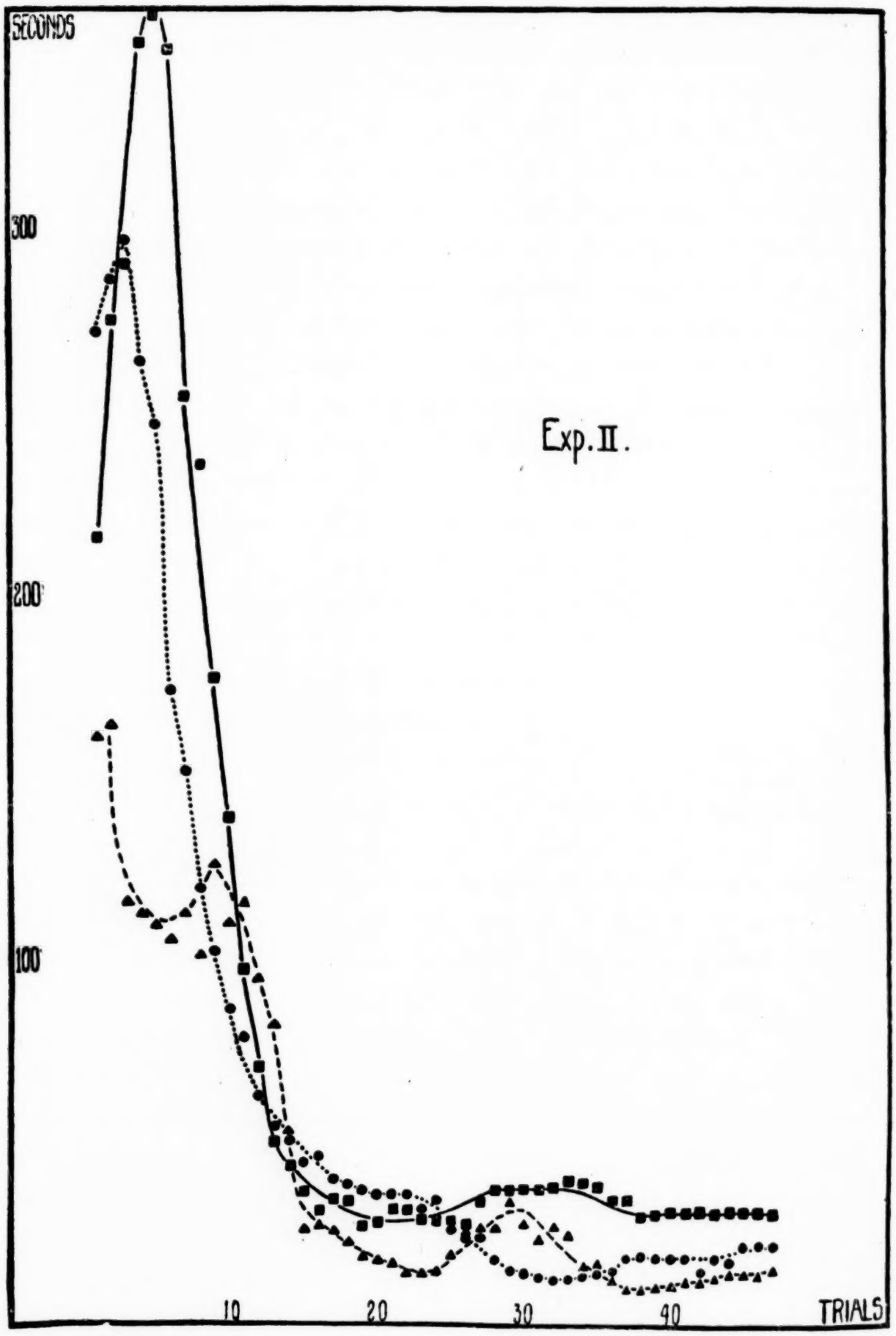
The total time elapsing between the entrance of the rat into the outer alley in the problem-box to the entrance into the food box after touching the inclined plane which automatically opened the door, was recorded. A trial was considered 'successful' when the rat proceeded directly to the plane, touched it so as to make the contact, and then proceeded directly to the food box. These rats were given one trial per day for 50 consecutive days. Table IV. shows the number of rats that completed this task; the remainder died of various causes.

TABLE IV

| | Completed 50 Trials | Original Group |
|---|---|---|
| Control | 18 | 20 |
| Pituitary | 15 | 20 |
| Adrenal | 17 | 20 |

The important criterion in scoring results with the problem-box is *time*. Table V. shows the total time taken by each rat in completing 50 trials. Taking average results, the pituitary group took least time, the adrenals the longest and the normals intermediate. The adrenal group shows a much wider range and greater degree of scattering. The normals seem to be concentrated toward the shorter times.

If the values are plotted in the form of a learning curve (see Graph 1), the following results are in evidence. The pituitary group begins with the lowest times but shows marked irregularity in the form of the curve. The adrenal group begins intermediate in rank but soon shows the longest times of all three groups. In the middle region of the curve all groups are so intermixed that no ranking is possible. Toward the 35th trial and continuing to the end of the curve, however, the three curves show what may be a constant




GRAPH I. Learning curves compiled from data of experiment 2. Each large symbol represents the average time per rat per trial. The circles denote the control rats; the squares denote the adrenal rats; the triangles denote the pituitary rats. Curves are somewhat smoothed.

tendency,—namely, the adrenals with a longer time than the other two and the pituitary with the shortest time. The difference, however, is small.

## TABLE V

RECORD OF RESULTS FOR EXPERIMENT 2

| | Control | Pituitary | Adrenal |
|---|---|---|---|
| Time per rat per 50 trials in seconds..... | 981<br>1,089<br>1,238<br>1,525<br>1,782<br>2,009<br>2,220<br>2,245<br>2,321<br>2,502<br>2,591<br>2,620<br>2,890<br>3,920<br>4,172<br>4,629<br>6,028<br>14,922 | 362<br>508<br>928<br>964<br>1,170<br>1,189<br>1,282<br>1,345<br>1,560<br>2,029<br>2,624<br>3,590<br>4,826<br>6,501<br>8,489 | 542<br>927<br>969<br>1,230<br>1,622<br>1,765<br>1,801<br>2,008<br>2,103<br>2,540<br>4,621<br>7,140<br>7,290<br>7,306<br>8,152<br>11,670<br>15,923 |
| Total..... | 59,685 | 37,367 | 77,599 |
| Average..... | 3,316 | 2,491 | 4,564 |
| Number of rats..... | 18 | 15 | 17 |
| Number of trials to<br>first P. T.....<br>second P. T.....<br>third P. T..... | <br>29.6+<br>38.3+<br>41.3+ | <br>23.2<br>29.3<br>35.1 | <br>32.3+<br>38.0+<br>44.0+ |
| Number of animals that did not make<br>1 P. Trial.....<br>2 P. Trials.....<br>3 P. Trials.....<br>Number of perfect trials per rat per 50 trials..... | <br>1<br>5<br>8<br>3.2 | <br>0<br>0<br>0<br>8.0 | <br>4<br>7<br>10<br>3.3 |

For purposes of comparing the groups by an additional criterion, it was arbitrarily decided that if a rat went to the inclined plane immediately upon admittance to the problem-box and after springing the latch went directly to the food box, this performance should be called a 'perfect trial' and so indicated in the records.

Referring again to Table V. it will be seen that the pituitary group not only takes fewest trials to attain each criterion, but all 15 rats make at least 3 perfect trials. The record of the adrenal group is again the poorest, being lowest in every case except with 2 perfect trials where it is slightly better than the control group.

## Experiment 3

Since the results, although consistent, had up to this time been far from convincing, it was decided to attempt to exaggerate the effect in some way. It was thought that by inbreeding the groups there might be a possibility of some cumulative hereditary effect which would manifest itself by more striking differences between the three groups. To investigate this problem the following experiment was devised.

The rats which survived the previous experiment were now inbred as to groups, feeding of the extracts being continued during pregnancy and lactation. The litters of the three groups were carefully kept apart and from these a third set of groups was compiled. The progeny of the Control group were now fed the Brain Tissue; those of the pituitary group fed anterior pituitary, and those of the adrenal group fed adrenal cortex. The technique of weighing, feeding, running, etc. was identical with the previous experiment. The same problem-box was used as the learning task. The number of rats employed is shown in Table 6.

## Table VI

| Exp. 3 | Number Completing 50 Trials | Number Beginning Experiment |
|---|---|---|
| Control | 21 | 21 |
| Pituitary * | 4 | 4 |
| Adrenal | 18 | 21 |

The results from Experiment 3 were dealt with in the same way as in Experiment 2. Reference to Table 7 will

* It was found impossible to breed the pituitary group while feeding anterior pituitary extract. The feeding was withheld until 5 litters were born and then resumed. The mothers promptly refused to feed the young, with the resulting death of all but 9. The feeding was withheld again but only 4 survived to partake in the experiment.

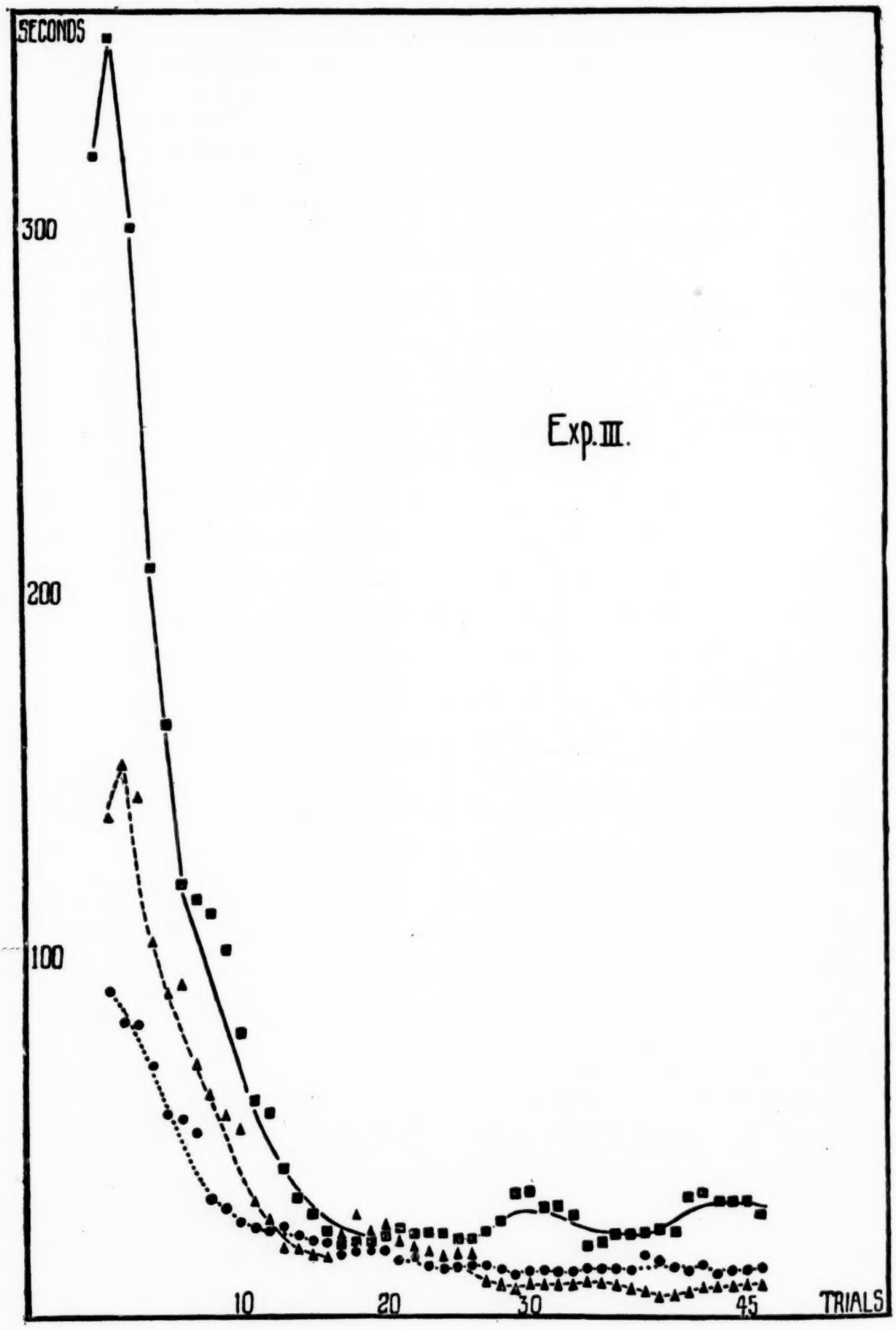
## TABLE VII

RECORD OF RESULTS FOR EXPERIMENT 3

| | Control | Pituitary | Adrenal |
|---|---|---|---|
| Time per rat per 50 trials in seconds..... | 368<br>512<br>825<br>864<br>892<br>954<br>982<br>1,025<br>1,069<br>1,125<br>1,162<br>1,290<br>1,295<br>1,348<br>1,409<br>1,522<br>1,864<br>2,062<br>2,143<br>3,829<br>4,028 | 1,022<br>1,575<br>2,081<br>2,532 | 1,061<br>1,142<br>1,285<br>1,306<br>1,821<br>2,069<br>2,123<br>2,562<br>3,098<br>3,641<br>3,902<br>5,065<br>5,098<br>5,721<br>5,875<br>7,501<br>8,898<br>9,927 |
| Total..... | 30,568 | 7,210 | 71,495 |
| Average..... | 1,455 | 1,802 | 3,972 |
| Number of rats..... | 21 | 4 | 18 |
| Number of Trials to<br>1 Perfect Trial.....<br>2 Perfect Trials.....<br>3 Perfect Trials..... | <br>26.9+<br>32.9+<br>38.5+ | <br>15.7<br>28.2<br>34.5+ | <br>29.9+<br>35.4+<br>42.5+ |
| Number of animals that did not make<br>1 P. T.....<br>2 P. Trials.....<br>3 P. Trials.....<br>Number of Perfect Trials per rat per 50 Trials..... | <br>3<br>5<br>6<br>4.0 | <br>0<br>0<br>2<br>6.9 | <br>6<br>7<br>11<br>2.5 |

indicate the total time taken by each rat to complete 50 trials. Here the normals have the lowest score; the pituitary intermediate; and the adrenals markedly the highest. The adrenal group shows the widest range and scattering. The pituitary group composed of only 4 rats cannot be considered very seriously. The pituitary group, however, again shows the best 'perfect trial' record with the adrenal group last.

The learning curve, Graph 2, compiled as in the previous experiment, shows the following points: The control group




GRAPH II. Learning curves compiled from the data of experiment 3. Symbols as in Graph I.

start out with the lowest time, the pituitary (only 4) intermediate, and the adrenals by far the longest. The same complexity obtains in the medial portions of the curves, but about the thirtieth trial the same relationship ensues and persists as occurred in the former graph, viz., the adrenal group with the longest times, the control group intermediate and the pituitary with the shortest times.

It should be pointed out that the pituitary group, small as it was, started out with a physical handicap due to poor nutritional care when young, as can be seen by their lower initial weight (Graph 5) at corresponding ages to the adrenal and control groups, *i.e.*, 30 days old.

## Experiment 4

### Table VIII

| | | Exper. 2, 1st Generation | Exper. 3, 2d Generation | Per Cent. Improvement |
|---|---|---|---|---|
| Average Time | Control..... | 100% | 100% | 128 |
| | Pituitary..... | 75 | 124 | 38 |
| | Adrenal..... | 131 | 273 | 12 |
| Trials to First Perfect | Control..... | 100% | 100% | 10 |
| | Pituitary..... | 78 | 58 | 41 |
| | Adrenal..... | 109 | 111 | 8 |

An examination of Table VIII. shows some interesting relationships. The records of the rats of the 3 groups in experiments 2 and 3 have been tabulated for 2 criteria, viz., average time per 50 trials and number of trials to the first perfect trial. In the first 2 columns under the heading 1st generation and 2d generation, the records of the control group were taken as 100 per cent. and the relationship of the other 2 groups calculated upon this basis. In the third column the percentages of improvement of the records of the second generation over the first are tabulated.

In Experiment 2 the percentage values point to a superiority of the pituitary group and an inferiority of the adrenal group when compared with the control. Turning to the second generation we find the same relationship holding true except for the pituitary group in the time values. In the

other criterion the effect is exaggerated in the second generation, as it is for the trials to second and third perfect trials (not shown in this table).

The third column shows the comparison of the records of the second generation with the first and it is seen that in *all* cases there is superiority of the second generation.

The rats in both experiments were bred in the laboratory; they were fed the same dose of gland tissue under the same experimental conditions. The difference lay in the fact that the parents of the second generation had been fed gland tissue and also had run the problem-box. Whatever effect is noted must be correlated with these two differences.

One can conjecture that if the effect of feeding the tissues would influence the offspring, then the specific effects would be exaggerated. Hence we would find the pituitary group relatively much better than the control and the adrenal group relatively much worse. This is not unambiguously shown by the records.

However, if there is a transference of the problem-box response (acquired characteristics), then the second generation would be much better than the first and this influence would serve to level out the differences between the groups, counteracting the adrenal influence especially.

It was decided at the beginning of the third experiment to run an additional control group of 21 normal rats bred in the laboratory from rats that had not been fed any of the tissues nor had they run the problem-box. The rats corresponded to the control group of Experiment 2 in ancestry. They were subjected to the same experimental technique as the other rats in experiment 3 with the exception of the special feeding. They were fed only bread and milk and occasionally sunflower seeds, which was the diet of the other rats, without the gland tissues.

## TABLE IX

AVERAGE TIME PER RAT PER 50 TRIALS

| | |
|---|---|
| Control Exp. II | 3316 |
| Control Exp. III | 1455 |
| Normal Exp. IV | 3252 |

Table IX. shows a significant relationship. The extra control group, called the normal group, approximates the first generation rather than the second in its time record, indicating that the improvement of the second over the first generation is a valid assumption.

The data at hand are too meager to justify any confident conclusions and are submitted here as a suggestion for further investigation.

## Physiological Results

*Gland Weights.*—In all three experiments as soon as the rats had served their purpose of learning or breeding, they were killed and the adrenal and pituitary glands carefully dissected out and weighed. They were then fixed for histological examination.[1]

### Table X

**Weights of Dissected Adrenal Glands**

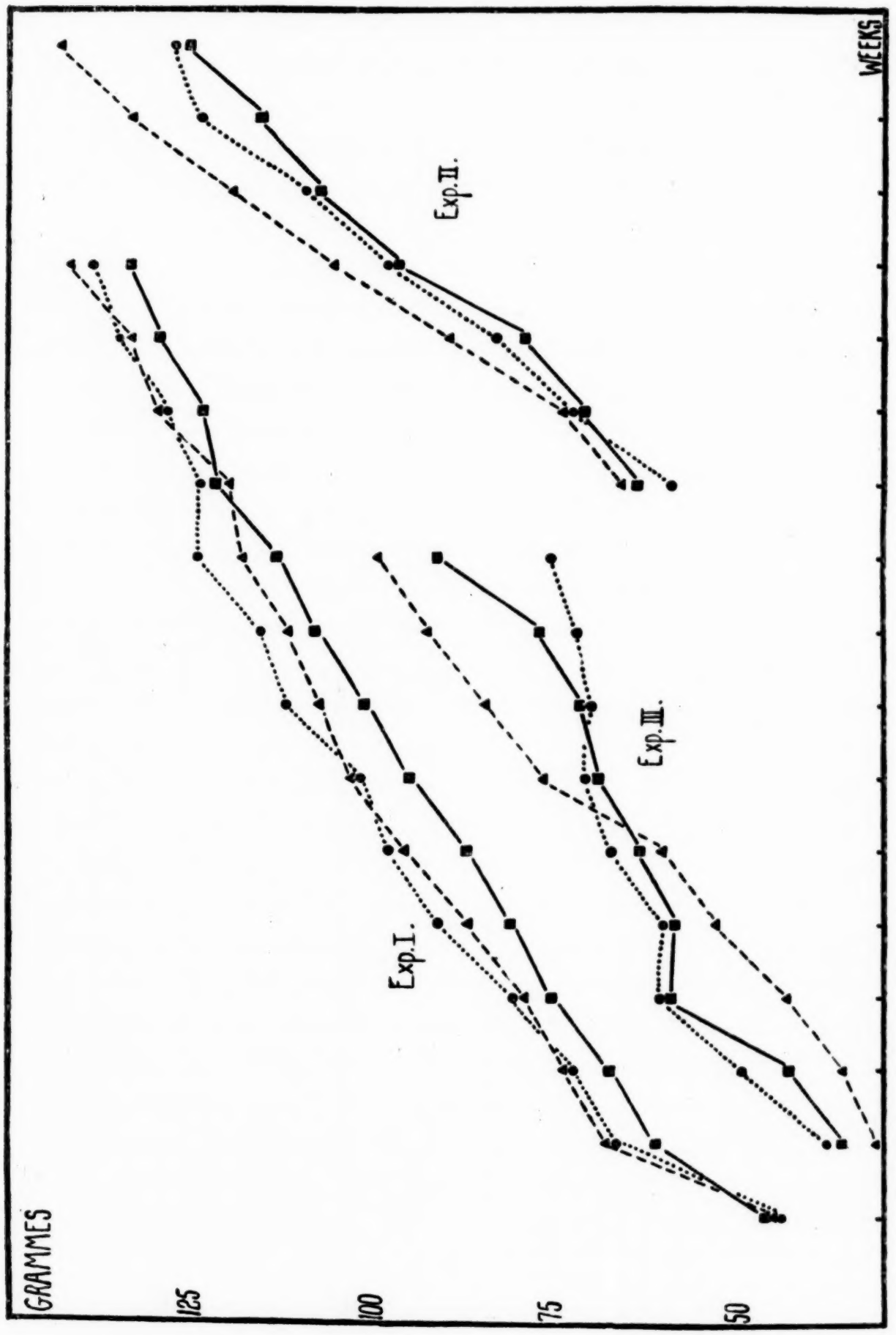
Values represent mgms. per 100 gms. body-weight.

Figures in brackets represent the number of rats in the group.

| | Aver. | Min. | Max. |
|---|---|---|---|
| Exp. 1 | | | |
| Controls (7) | 12.2 | 11.5 | 14.0 |
| Pituitary (4) | 23.9 | 16.5 | 28.5 |
| Adrenals (4) | 15.9 | 14.3 | 17.1 |
| Exp. 2 | | | |
| Controls | | | |
| Male (2) | 10.8 | 10.8 | 10.8 |
| Female (7) | 20.9 | 11.7 | 24.6 |
| Pituitary | | | |
| Male (2) | 12.2 | 11.7 | 12.8 |
| Female (9) | 18.3 | | |
| Adrenals | | | |
| Male (2) | 12.4 | 12.3 | 12.4 |
| Female (9) | 19.7 | 13.3 | 26.6 |
| Exp. 3 | | | |
| Normal | | | |
| Male (10) | 12.1 | 9.6 | 20.8 |
| Female (11) | 15.8 | 13.8 | 17.9 |
| Adrenal | | | |
| Male (5) | 15.3 | 12.4 | 18.4 |
| Female (10) | 18.5 | 16.6 | 25.5 |

It will be seen from Table X that the adrenal and pituitary fed rats show a definite increase, in weight of adrenal glands,

[1] Lack of time prevented the authors from completing the histological investigation. The tissues are fixed and cleared and await imbedding, cutting and examination.




GRAPH III. Curves represent the increase in body-weight of the rats in the three experiments. All the rats were weighed at thirty days of age and then weekly until the close of the experiment. Each large symbol represents the mean of the weights of all the rats in the respective group for the one weekly weighing. Symbols as in Graph I.

over the control rats. In the second experiment, the females were either pregnant or had just been delivered of a litter and hence the adrenal weights are inconclusive. As the total weight of the pituitary gland is about .005 gm. the error in weighing overshadows any variation due to feeding, etc. Hence these values are not given. (See Smith (5) for effect of pituitary feeding on reproductive organs in rats.)

*Body Weight.*—The weights of the rats of one group were added together each week and the arithmetical mean calculated. These were then tabulated as shown in Graph 3. The data for rats of each experiment were kept separate giving three curves, *A*, *B*, and *C*, corresponding to Experiments 1, 2, and 3.

There are no definite indications, but there seems to be a tendency for the adrenals to lag behind and probably a tendency for the pituitary rats to be heavier towards the end of the experimental period.

*Reproduction.*—That there was a definite interference in the sexual functions of the pituitary groups was indicated by the fact that it was found impossible to inbreed them. While the anterior pituitary was being administered the females did not become pregnant. After discontinuing the feeding for two weeks 5 of the females became pregnant and were delivered of litters. Four of the mothers refused to suckle their young until the anterior pituitary feedings were again discontinued. This feeding was then discontinued but there were only four survivals of all five litters. Hence the records of pituitary group in the third experiment must be considered in the light of these facts.

*Pathological Effects.*—It was observed that at times the adrenal rats showed digestive disturbances in the nature of short attacks of diarrhœa. Several of the laboratory rats were placed in a separate cage and fed as much of the extract as they would take. They rapidly showed signs of this condition and succumbed in a few days. The effect is aggravated by hot weather, during which the adrenal group required and received more water than the others. Whenever the condition was perceived the dosage of the extract was reduced until recovery was apparent.

## TABLE XI

RANKING OF THE 3 GROUPS IN EXPERIMENTS 1, 2 AND 3

| Criteria | | Control | Pituitary | Adrenal |
|---|---|---|---|---|
| Table 3, Exp. 1 | | | | |
| Trials: Complete | | 2 | 1 | 3 |
| Incomplete | | 3 | 1 | 2 |
| Av. time per rat | Gross complete | 2 | 1 | 3 |
| | Static complete | 2 | 1 | 3 |
| | Net complete | 2 | 1 | 3 |
| Av. time per rat | Gross complete | 2 | 1 | 3 |
| | Static complete | 2 | 1 | 3 |
| | Net complete | 2 | 1 | 3 |
| Av. time per trial | Gross complete | 2 | 1 | 3 |
| | Static complete | 2 | 1 | 3 |
| | Net complete | 1 | 2 | 3 |
| Av. time per trial | Gross incomplete | 2 | 1 | 3 |
| | Static incomplete | 2 | 1 | 3 |
| | Net incomplete | 1 | 2 | 3 |
| Av. time last 3 trials | | 2 | 1 | 3 |
| Errors per rat | For. comp. | 2 | 1 | 3 |
| | Back. comp. | 1 | 1 | 3 |
| | Ret. comp. | 2 | 1 | 3 |
| | For. incomp. | 2 | 1 | 3 |
| | Back. incomp. | 2 | 1 | 3 |
| | Ret. incomp. | 2 | 1 | 3 |
| Av. total errors per trial | Comp. | 2 | 1 | 3 |
| | Incomp. | 2 | 1 | 3 |
| Table 5, Exp. 2 | | | | |
| Av. time | | 2 | 1 | 3 |
| Trials to 1st P. T. | | 2 | 1 | 3 |
| 2d P. T. | | 3 | 1 | 2 |
| 3d P. T. | | 2 | 1 | 3 |
| Number of perfect trials per rat | | 3 | 1 | 2 |
| Table 7, Exp. 3 | | | | |
| Av. time | | 1 | 2 | 3 |
| Trials to 1st P. T. | | 2 | 1 | 3 |
| 2d P. T. | | 2 | 1 | 3 |
| 3d P. T. | | 2 | 1 | 3 |
| Number of perfect trials per rat | | 2 | 1 | 3 |
| Totals | | 66 | 36 | 96 |

## CONCLUSIONS

Table XI. shows in tabular form the tendency for the pituitary group to be superior throughout the experiment and for the adrenal group to be inferior.

The physiological effects have been such as to leave little room for doubting that the feeding of these tissues had an

active influence. The change in gland weights, the alteration of body weight, the effect upon the reproductive system (pituitary) and the digestive disturbance (adrenal) all point to an effect, however difficult it may be to isolate any of the factors or to explain the results.

One can assume one of two attitudes towards the above data: (*a*) the differences shown are not of sufficient magnitude to be valid for such small groups; or (*b*) the differences are small but sufficiently consistent to denote a tendency toward superiority of the pituitary fed rats and inferiority of the adrenal fed rats; the physiological results at least point to some effect upon the rats and hence a psychological influence would not be surprising.

If further and more searching statistical inquiry shows the former to be the more likely conclusion then there is nothing more to say; if, however, the latter view be the more enticing it at least opens up the question for further inquiry and interesting discussion.

Let us assume the latter to be true. How, then, can one attempt to explain the results?

It must be remembered that the learning process here depicted is a matter of conditioning certain responses to the environment and depends fundamentally upon an intact and healthy nervous system for proper functioning.

Taking up first the question of adrenal inferiority, the following suggestions are applicable:

1. It was found that increasing the dosage induced certain digestive disturbances the most serious being a severe diarrhœa, which, if not controlled by cessation of feeding eventuated in death. Might not then the feeding of adrenal cortex have a definitely detrimental effect on the general health and well-being indirectly affecting the nervous system?

2. The rats did not like the taste of the adrenal tissue (at least it was more difficult to get them to eat it) and this may have led them to eat more sparingly of the food given later. This may give rise to two resulting conditions. (*a*) This group may have been relatively undernourished when compared to the other two groups. (*b*) Since 'food' was used

as the incentive for inducing the rats to run the maze and problem-box, this circumstance may have altered this important factor. Liddell states: "The validity of any conclusions which may be drawn from the behavior of normal and thyroid-ectomized sheep in the maze either during learning or after its completion when reaction-times are being measured, depends on the continued efficacy of the incentives which condition the animal's behavior" (p. 197, *Quart. J.*).

3. There may have been an effect produced by the specific physiological substance itself. Cameron has sought to demonstrate an antagonistic action between the adrenal cortex and the thyroid secretion. It is generally held that the thyroid is intimately concerned with the growth of 'intelligence.' Hence the feeding inhibited the thyroid activity producing less intelligent rats.

In discussing the superiority of the pituitary one must seek for some positive rather than negative effects. Undernourishment or induced bad health or lack of motive cannot account for increased efficiency. The following suggestions are offered:

1. The tissue extract may have acted as a new and stimulating food protein increasing the general organic activity.

2. Since all of the comparisons were made with the records of the control rats we should be sure that feeding brain tissue does not affect the rats as an improper food as suggested for the adrenals, thereby reducing their efficiency. This being true then the pituitary records would represent normal rats, and the feeding would be at best harmless. (No deleterious effects could be noted by increasing the dose of the brain tissue. The rats seemed to eat the mixture without hesitation. A group of 20 rats were run coincidently with the second generation and fed only bread and milk. Their records are not included above. They closely approximated the control group of the first generation and were inferior to both the pituitary and the control group of the second generation. Hence we may conclude that the control group was not injured by the feeding.)

3. There is evidence (1) to show that some components of the anterior pituitary does increase the general metabolic rate and has a stimulating effect upon growth. This effect may have been produced and have indirectly affected the nervous system advantageously.

It seems to the authors that the results of this paper need verification before any serious conclusions may be drawn It seems, however, that the data justify the time and work that have been expended thereupon. We wish to take this opportunity to express our appreciation of the splendid co-operation that exists between the departments. We are grateful to the department of Anatomy for affording us the facilities of their laboratories for doing the dissection. Professor Carlson of the department of Physiology assisted us materially with advice and criticisms. We wish also to thank Professor Carr and Professor Robinson, whose co-operation made the experiment possible.

## Bibliography

1. Cameron. International Congress of Physiologists, Edinburgh, 1923.
2. Goetsch. *Johns Hopkins Hospital Bulletin*, 1916.
3. Liddell and Simpson. *Proc. of Soc. Experimental Biology and Medicine*, 1922, XX., 197–8.
4. Liddell. *Ibid.*, 1922, XIX., 343–4.
5. Liddell. *Ibid.*, 1922, XIX., 423–5.
6. Liddell. *Quarterly Journal of Experimental Physiology*, XIII., 1923, 191–7.
7. Marinius, C. S. *American Journal of Physiol.*, 1919, *49*, 258.
8. Robertson, T. B. *Journal of Biological Chemistry*, 1916.
9. Schaeffer. The Endocrine Organs, 1916.
10. Smith, C. S. University of Chicago, Unpublished Thesis, 1921.
11. Stewart, G. N. *Endocrinology*, *5*, 1921, 297.
12. Wheeler and Vincent. *Endocrinology*, *1*, 1917, 140.
13. Warden. Comp. Psychol. Monog. *1*, 1923.

# PSYCHOLOGICAL TESTS IN ADVERTISING

BY A. T. POFFENBERGER

*Psychological Laboratory, Columbia University*

The Association Test as applied to advertising has been critically examined in a report published in the JOURNAL OF EXPERIMENTAL PSYCHOLOGY, October, 1923, by D. A. Laird. This investigator conducted an association test in which the stimuli were fifteen general commodity names, such as, shoes, chewing gum, tooth paste, etc., and in which the response was to be the first brand name of such a commodity that the subject could recall. This test, given to about fifty subjects, was followed three days later by another test in which the same subjects responded, not this time with the first brand name that could be recalled, but with the brand name of the article actually used by the subject. After an interval of four months the first experiment was repeated on as many of the original group as could be reached.

Two facts of considerable importance stand out as the result of this study:

1. There is a discrepancy between brand name recalled and brand used, or between association reaction and use. Disregarding sex differences and combining the records for men and women, it appears that there is agreement in 58.2 per cent. of the cases and disagreement in 41.8 per cent. of the cases. (Although the author says: "Again we find the disagreement greater than the agreement.")

When the commodities are grouped into three classes, namely, clothing, other essentials, and luxuries, it is reported that the agreement is greatest in the case of "other essentials," next in the case of "luxuries" and least in the case of "clothing."

2. When the two association tests conducted over an interval of four months are compared, subject by subject, there is a lack of consistency. The per cent. of the cases in

which there was agreement between first and second test was found to be for the men 48 and for the women 62.

From the author's conclusions I wish to quote the following passages: Concerning the relation between association and use he writes: "In no instance, however, is this agreement great enough to give validity to the *association tests as a final test of the measure of an advertising series*" (p. 360).[1] Concerning consistency he writes: "This consistency, or rather lack of it, casts grave doubts upon the validity of the application of association tests in practical situations" (p. 364). Finally, "From both types of experiment we must conclude that, while the association tests may be invaluable to the structuralist in ascertaining how the mind is composed, they do not carry over with equal value to the practical situation such as is presented in advertising. There is many a slip between the thought and the purchase, which is really important in the commercial field, and which is glossed over in an association psychology of advertising. The association test in this field denies the existence of the very things of permanent importance" (p. 365).

This severe condemnation of one of our highly respected and much used psychological techniques seems to imply that investigators have employed it to determine the extent to which certain branded commodities are used. Looking through the most important studies of this type I have failed to find an instance where the author states his problem to be the discovery of extent of use by way of the association test. For example, in the most extensive study of this nature, by Hotchkiss and Franken,[2] I find the method described as "The Association Method of Testing Brand Familiarity (Title of Chapter 2). The following statements are further indicative of the authors' purpose: "Such a study of the *public mind* has recently been made with respect to one hundred typical commodities. The results indicate *the degree to which the public is familiar with names and brands*,

[1] Italics here and in the quotations to follow are mine.

[2] 'The Leadership of Advertised Brands,' published by Doubleday, Page and Co., for the Associated Advertising Clubs of the World, 1923.

*and which brands are more generally known in each field.* By careful analysis of these results it may be possible to discover something of the causes which are responsible for *leadership in the public mind*" (p. 7).

"Certain manufacturers seem to have a clear leadership in their respective fields, at least so far as *public recognition is concerned*" (p. 12).

"In view of all these facts, a manufacturer who wishes to be *well known by the public* may well be concerned in discovering to what extent his efforts have been successful" (p. 6).

That the writers were aware of the possibility of careless interpretation of their results is indicated by the following significant statement: "*It must be remembered that the facts secured were merely the relative strength of associations and relative familiarity with names and brands. The subjects were not asked what brands they used or preferred. Any indication of the position of different manufacturers with respect to actual sales or good will are inferences only*" (p. 19).

H. F. Adams [1] writes thus in his chapter on Association: "It is imperative therefore that the advertiser should know how to *make his advertisements remembered by the reader.* Since the basis of all memory is association, it is necessary that we understand the laws of association, both the formation of associations and the laws of recall" (p. 153).

Discussing the association experiment as he applied it to advertising, he says: "This experiment also shows the relative strength of the different associations which have been connected with any one class of objects. It is in reality a measurement of the advertisements which have been most effective with any given individual" (p. 182). The context compels us to interpret this last sentence as referring to the effectiveness in establishing associations and not in making sales. Geissler [2] found that use was an important factor in determining familiarity but did not attribute a like potency to familiarity in determining use. Hotchkiss and Franken also note this influence of use upon familiarity (p. 32).

[1] 'Advertising and its Mental Laws,' Macmillan, 1920.

[2] *Jour. of Applied Psychology*, 1, 1917, 275.

It should not be surprising to find no cases where the association test was used as a measure of use, for there is a method of getting that information which is very much simpler and more direct, namely *to inquire directly about use.* This is very commonly done. For example, in reading over the sample questionnaires presented by Starch [1] one finds such questions as the following: (Concerning the purchase of raisins) If in package, what brand or brands? (p. 150). Also in the same questionnaire we find the following question: With what other brands of raisins are you familiar? Starch clearly recognizes the difference between familiarity with a brand and the use of that brand. In another questionnaire we find this question: What brand of dentifrice do you use? In still another: What make of fountain pen does party use at present time? This is followed by: What makes of fountain pens can party name without suggestion? Such information appears to be easy enough to get directly from people without the use of any semi-Freudian technique.

Why then, one may inquire, should a psychological test applied to advertising be condemned because it will not do what it was not intended to do? On the same grounds the Schick test for diphtheria susceptibility might be condemned because it is an unsatisfactory test for syphilis. Yet its value for its own purpose is unquestioned.

If the association test will not measure use, will it serve any other useful purpose for the advertiser? The data reported by Laird enable us to answer that it will serve a number of useful purposes. A few of these will be considered.

1. It will indicate the strength of the associations between a commodity and a brand name. A surprisingly large proportion of modern advertising is of the so-called publicity sort, and is intended to create familiarity with brand names. The degree of familiarity of various brand names for a certain commodity is a matter of considerable importance. It measures, in a way, the effectiveness of the advertising in establishing such associations. Adams reports that "one of the most striking results of the experiment is the fact that

[1] 'Principles of Advertising,' A. W. Shaw Company, 1923.

those commodities which are mentioned most frequently are, with few exceptions, the ones which are most widely advertised. A second point which is very striking is the number of times an advertised commodity was not thought of" (p. 194). Both these points are of interest. It would appear that one might thus discover the commodities where new brand names could be created with least resistance from names already established and familiar to the public. And to know that amount of advertising and degree of familiarity are closely related is quite worth while. To know *how* closely related would be more important, and to analyze the cases where there is a discrepancy between amount of advertising and degree of familiarity would be still more important. Much light might be thrown upon the effectiveness of publicity devices by such a study.

2. The discovery of discrepancies between familiarity and use constitutes the most valuable contribution that Laird has made, although these discrepancies were the primary cause of his condemning the test. The search for the causes of discrepancy, and the analysis of special cases of discrepancy should furnish much valuable data for the advertiser. Laird has pointed out some of these causes, but there are still others.

(*a*) One of the most prevalent causes of the discrepancy between familiarity and use is the very character of much of our modern advertising. Its sole function seems to be to keep a brand name before the public to make it familiar, to impress it upon the memory. Criticism of advertising of this sort, sometimes called "poster" advertising is very frequent. Now, it must be recognized that there is a difference between remembering or being familiar with an article and being convinced of its value, that it is the thing to use. The former may very well exist without the latter. The former depends upon complying with the so-called laws of association, the most important of which are frequency of experience, and vividness of experience or strength of the impression. To arouse conviction regarding the value of a commodity is quite a different matter.

A study of cases of agreement over against the cases of disagreement between familiarity and use, together with an examination of the advertising used in both cases might do much to show which advertising devices do and which do not produce conviction as well as memory. The clear understanding of the discrepancy between familiarity and use and its conditions would alone, I believe, justify the use of the association test in advertising work.

(*b*) A cause of discrepancy suggested by Laird is the financial status of the subject taking part in the experiment. "There is many a slip between the ad and the lip. These slips may be caused by economic reasons. Especially is this true in the group of subjects used. In most instances they were squeezing an educational opportunity out of limited funds; most of them had to rub the eagle some time before they parted with him. In this they are probably representative of the great bulk of purchasers" (p. 362).

There is great question whether the group of people studied in this experiment constitute an adequate sampling of the population as far as economic status is concerned. Conclusions should not be drawn from an inadequate sample. But, if in the case of any particular commodity, a discrepancy between familiarity and use should appear and further analysis of this discrepancy showed it to be due to the high cost of the article, such information would be of great value, and the remedy for the discrepancy would be clear. Advertising must convince the public but the public must also have the capacity to purchase what it is convinced it should have. This is a fundamental rule of marketing, the adjustment of price to purchasing power, which no distributor would knowingly defy.

(*c*) Habit may be in part responsible for discrepancies between familiarity and use. The advertiser should learn to know the strength of habit if he is to take measures to overcome it. One may be convinced that a new tooth paste is better than the one he is now using and yet habit will bring about the continued use of the old one. Comparison and analysis of the advertising in cases of agreement and dis-

agreement between "thought habit" and "use habit" may point the way to effective means of dislodging old habits of use in favor of new ones.

(*d*) Another cause of discrepancy which deserves consideration in a study of this sort is the frequency with which purchases are made. Suppose, for instance, that a person buys a watch once in a lifetime. Then after his purchase has been made, there may well develop a discrepancy between familiarity and use and even between conviction of value and use through efficient advertising. Still, the purchaser may not dispose of his old watch and buy the new one. The three cases of closest agreement between association and use were for men the associations with tooth paste, cigarettes and chewing gum. Such articles offer good opportunity for use to keep pace with familiarity accompanied by conviction. Lack of frequency of purchase should not be thought of as introducing an error into the association test. It constitutes, rather, a factor whose importance in producing a discrepancy between association and use should be investigated in the case of various commodities.

(*e*) Another possible source of discrepancy lies in the distribution of nationally advertised products. One must make his purchases from the kinds of commodities available in his locality but may derive his familiarity with trade names from the reading of nationally distributed magazines. The cases showing least agreement between familiarity and use in the material studied by Laird were candy and fountain pens. (Figures for men only.) The geographical distribution of his subjects although not given in this report, might form the basis for the interpretation of these figures. A study of the discrepancies between familiarity and use for different commodities according to geographical location might reveal interesting material in this regard.

3. Not only does the discrepancy between familiarity and use offer very suggestive problems for the advertiser, but the lack of consistency between associations taken at intervals of four months may be equally serviceable. It is customary in studying the reliability of psychological tests

to have one group of people take the test more than once and to compare the various performances. If the performance of individuals does not vary from time to time, the test is said to be reliable and the results consistent. But in such cases the function measured is supposed to be stable and the conditions under which the test is given are supposed to be identical or nearly so. Now in the association test the function is not stable but is known to vary according to the accumulation of experiences. In such a test as the Kent-Rosanoff Free Association test the associative connections are well established because of their simple logical character and the frequency with which they have been experienced from early childhood. They are, therefore, fairly stable over long periods. In the case of associations established by advertising the conditions are often quite different. They are especially suitable for providing a rapidly varying experience. New advertising campaigns are launched to market new products, and old campaigns are modified to meet the new competition. Should one expect that relative familiarity of all or most brand names would remain unchanged during a period of four or five months? A new advertising campaign for tooth paste or chewing gum ought to show results in less than four months after the campaign is launched. In this constant war of competing brands degrees of familiarity must change if the advertising is effective. The fact that approximately 50 per cent. of the associations changed and that 50 per cent. remained the same over a period of four months should not be surprising or disturbing to the advertising investigator.

Such changes should not be looked upon as a source of error in the association test but rather as opportunities to measure changes wrought by advertisements in the reactions of a sampling of the public. When such changes are checked against the advertising used, interesting data may be acquired.

The foregoing statements are not intended to be a complete catalogue of the uses of the association test in advertising or even to include the most important uses. They are simply intended to show a few of the ways in which the test

might be usefully applied. For the writer at least, the study by Laird has not only not created the conviction that the association test in advertising is worthless, but on the contrary has revealed a wealth of possibilities in its use still untouched by experimenters, arising from the discrepancy between familiarity and use and between tests repeated after long intervals of time.

# A FORMULA TO CORRECT FOR THE EFFECT OF ERRORS OF MEASUREMENT ON THE CORRELATION OF INITIAL VALUES WITH GAINS

BY GODFREY H. THOMSON

*Teachers College, Columbia University*

## I. Theoretical Deduction

As Thorndike showed in a recent article, if there is no *real* correlation between an initial value of some mental function and its gain over a certain period, then because of errors of measurement, there will appear to be a negative correlation between these quantities *as measured*. And for the same reason, any real correlation there may be, will be reduced in the measurement.

$$\left.\begin{aligned} \text{Let } a &= \text{true initial value,} \\ g &= \text{true gain,} \\ a + g &= \text{true final value.} \end{aligned}\right\} \qquad (1)$$

Let $e$ = error of measurement in initial value,
$e'$ = error of measurement in final value.

Then if $x$ is the measured initial value,
and $y$ is the measured gain,
and $z$ is the measured final value (where $x + y = z$),

we have

$$\left.\begin{aligned} x &= a + e, \\ z &= a + g + e', \\ y &= g + e' - e. \end{aligned}\right\} \qquad (2)$$

The reason for the apparent negative correlation of $x$ and $y$, even if $a$ and $g$ are uncorrelated, is the presence of $+ e$ in $x$ and of $- e$ in $y$. On the assumption that $e$ and $e'$ are not correlated with one another or with $a$ or $g$ (assumptions similar to those made in using Spearman's attenuation formula) we then have the following derivation of the formula required:

$$r_{ag} = \frac{\sigma_a^2 + \sigma_g^2 - \sigma_{a-g}^2}{2\sigma_a\sigma_g} . \tag{3}$$

Now from equation (2) we have

$$\sigma_x^2 = \sigma_a^2 + \sigma_e^2, \tag{4}$$

$$\sigma_y^2 = \sigma_g^2 + \sigma_e^2 + \sigma_{e'}^2. \tag{5}$$

Also $(x - y) = (a - g) + 2e - e'$;

$$\therefore \quad \sigma_{x-y}^2 = \sigma_{a-g}^2 + 4\sigma_e^2 + \sigma_{e'}^2. \tag{6}$$

Substituting for $\sigma_a^2$, $\sigma_g^2$ and $\sigma_{a-g}^2$ from these last three equations in (3) we get:

$$r_{ag} = \frac{\sigma_x^2 + \sigma_y^2 - \sigma_{x-y}^2 + 2\sigma_e^2}{2\sqrt{\{(\sigma_x^2 - \sigma_e^2)(\sigma_y^2 - \sigma_{e'}^2 - \sigma_e^2)\}}} . \tag{7}$$

But

$$\sigma_x^2 + \sigma_y^2 - \sigma_{x-y}^2 = 2\sigma_x\sigma_y r_{xy}$$

and on substituting, this gives

$$r_{ag} = \frac{\sigma_x\sigma_y r_{xy} + \sigma_e^2}{\sqrt{\{(\sigma_x^2 - \sigma_e^2)(\sigma_y^2 - \sigma_{e'}^2 - \sigma_e^2)\}}} . \tag{8}$$

The only unknown quantities here are $\sigma_e^2$ and $\sigma_{e'}^2$. They can be found from the reliability coefficients of $x$ and $z$, respectively, thus:

Let $x_1$ be an alternative measure of $x$, and $e_1$ its error. Then the reliability coefficient

$$r_x = \frac{\sigma_x^2 + \sigma_{x_1}^2 - \sigma_{x-x_1}^2}{2\sigma_x\sigma_{x_1}} .$$

But

$$\sigma_x^2 = \sigma_a^2 + \sigma_e^2, \quad \text{since} \quad x = a + e;$$
$$\sigma_{x_1}^2 = \sigma_a^2 + \sigma_{e_1}^2, \quad \text{since} \quad x_1 = a + e_1;$$
$$\sigma_{x-x_1}^2 = \sigma_e^2 + \sigma_{e_1}^2, \quad \text{since } x - x_1 = e - e_1.$$

Therefore:

$$r_x = \frac{\sigma_a^2}{\sigma_x\sigma_{x_1}} = \frac{\sigma_a^2}{\sigma_x^2} . \tag{9}$$

And from (4)

$$\left.\begin{aligned} \sigma_e^2 &= \sigma_x^2 - \sigma_a^2 \\ &= \sigma_x^2 - r_x\sigma_x^2 \quad \text{from (9)} \\ &= \sigma_x^2(1 - r_x) \\ \text{and similarly} \quad \sigma_{e_1}^2 &= \sigma_z^2(1 - r_z). \end{aligned}\right\} \tag{10}$$

Substituting these values in equation (8), we have, after a slight rearrangement:

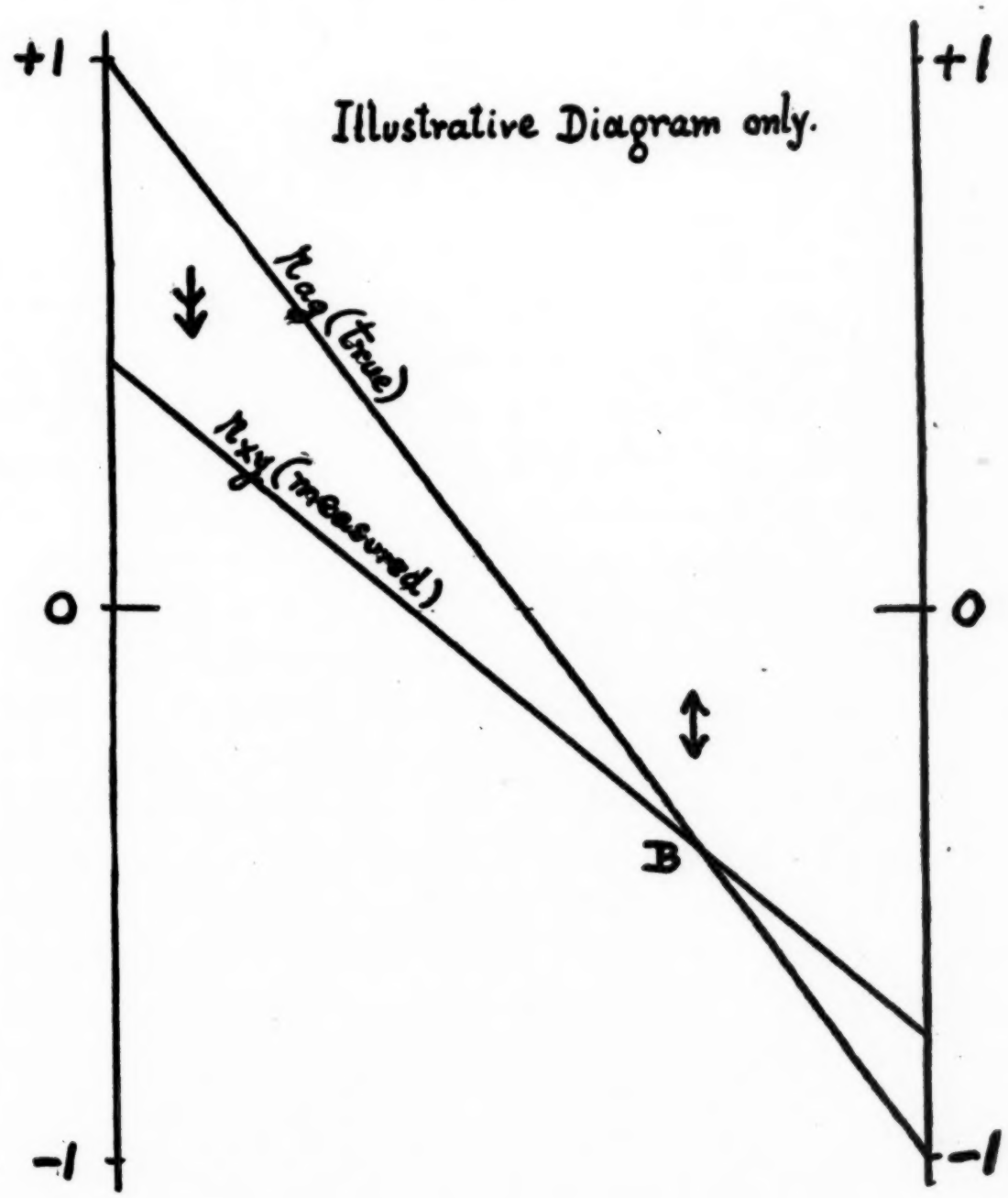
$$r_{ag} = \frac{r_{xy} + \frac{\sigma_x}{\sigma_y}(1 - r_x)}{\frac{1}{\sigma_y}\sqrt{r_x\{\sigma_y^2 - \sigma_x^2(1 - r_x) - \sigma_z^2(1 - r_z)\}}}, \qquad (11)$$

where $x$ is initial measured value,

$y$ is measured gain,

$z$ is measured final value,

and $r_x$ and $r_z$ are reliability coefficients.




It is of especial interest to consider in the light of this formula, how $r_{xy}$, the correlation of apparent initial value

with apparent gain, departs from $r_{ag}$ the true value, as the latter sinks from + 1 through 0 to − 1.

By a little algebra it can readily be found that

$$\sigma_x\sigma_y r_{xy} = \sigma_a\sigma_g r_{ag} - \sigma_e^2. \qquad (12)$$

If all the sigmas in this equation are imagined as remaining constant, while $r_{ag}$ and $r_{xy}$ are given various values, the relationship between the two is seen to be linear

$$r_{xy} = Cr_{ag} - D, \qquad (13)$$

where $C$ and $D$ are constant proper fractions. The two quantities will be related as in the adjoining diagram where corresponding values of $r_{xy}$ and $r_{ag}$ are vertically above each other. The apparent correlation $r_{xy}$ begins at a smaller value than $r_{ag}$ but sinks less rapidly, and the lines may cross, as in the case shown, somewhere below the zero value. Above the zero line the two factors which tend to make $r_{xy}$ differ from $r_{ag}$ both act downwards, one being the usual attenuation effect, the other the special effect here considered. Below the zero line these two factors are opposed, for the attenuation effect always tends inward to zero, the spurious gain effect always downward to − 1, as is indicated by the small arrows. And so there may be a point at which they balance, below which $r_{xy}$ is too large, *i.e.*, too far from − 1. Notice that $r_{xy}$ may be negative, while the true value $r_{ag}$ is positive.

The careful reader will not need to be warned that this diagram is merely illustrative and not to be used to correct any $r$: for the slope of the lines and the position of the crossing point $B$ will depend upon the sigmas of equation (12). The crossing point may indeed be off the figure entirely and the lines merely convergent. The formula (11) is the method to be used in converting an observed into a true correlation of gain with initial value, and it is only valid if the errors of measurement are uncorrelated with one another or with $a$ or $g$.